# The Side Effects of Quantitative Easing: Evidence from the UK Bond Market

by

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We examine the returns to UK government bonds before, during and between the phases of quantitative easing to identify the side effects for the market itself. We show that the onset of QE led to a sustained reduction in the costs of trading and removed some return regularities. However, controlling for a wide range of market activity, including issuance and QE announcements, we find evidence that investors could have earned excess returns after costs by trading in response to the purchase auction calendar. Drawing on economic theory, we explore the implications of these findings for both the efficiency of the market and the costs of government debt management in both the short and long run.

JEL: G12, G14, E43, E44, E52

Keywords: Quantitative Easing, Gilts, UK Bonds, Price Efficiency, Bond Investors

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## Abstract

We examine the returns to UK government bonds before, during and between the phases of quantitative easing to identify the side effects for the market itself. We show that the onset of QE led to a sustained reduction in the costs of trading and removed some return regularities. However, controlling for a wide range of market activity, including issuance and QE announcements, we find evidence that investors could have earned excess returns after costs by trading in response to the purchase auction calendar. Drawing on economic theory, we explore the implications of these findings for both the efficiency of the market and the costs of government debt management in both the short and long run.



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## 1. Introduction

The UK government bond market (the gilt-edged bond market, or gilts) has been the main financial market within which the Bank of England's Monetary Policy Committee (MPC) has undertaken its programme of asset purchases, funded by central bank money creation, known as Quantitative Easing (QE). By the end of the most recent phase of QE in March 2013, the Bank of England had completed £330 billion of purchases of gilts, amounting to just over one-third of the total nominal stock outstanding.

Existing research on the effects of the QE programme in the UK has focussed either directly on the impact on various macroeconomic aggregates, or indirectly on the economic effects by examining the implications for the economy of certain bond and other financial market effects. The aim of this paper is to examine whether there are side effects, beneficial or detrimental, for the bond market itself of it being the prime vehicle for the asset purchase programme. While the potential for the existence of side effects of the asset purchases has been acknowledged by policy-makers, for example,

> "The MPC did not explicitly use these purchases to signal future intentions, … . Nor were its actions focussed on improving the functioning of gilt markets where liquidity premia, even in stressed times, were considered to be small." (Joyce et al, 2011)

there has been no direct attempt to identify whether such effects were experienced during the UK QE programme.

This research question is important because of the other key function of the gilt market; it is the main debt instrument used to fund the UK government's spending deficit. The stated aim of the UK Treasury's debt management policy objective is:

> "to minimise over the long term, the costs of meeting the Government's financing needs, taking into account risk, whilst ensuring that debt management policy is consistent with the aims of monetary policy". (UK Debt Management Office, 2013).

If QE affects the market in ways that could also reduce the cost of debt issuance, these would be clear beneficial side effects of QE. By contrast, if QE adds to the costs of debt issuance then this potentially compounds the economic woes that QE is attempting to fix. We are particularly motivated to understand such side effects because of the separation of policy responsibilities between the UK Treasury and the Bank of England. As the Bank of England has operational independence in the conduct of monetary policy, the Treasury has no choice but to accept the consequences of QE activity for the costs of debt issuance. The Treasury may feel further constrained in that, in order not to damage the objectives and the credibility of the Bank's QE policy, it may choose not to undertake any mitigating activity within its debt issuance programme. Our study, therefore, seeks to identify whether there is evidence that QE may have put any pressure on the costs of debt issuance.

The approach that will be taken to identify the side effects of QE is to examine the behaviour of the returns to gilt investment and the costs of trading for gilt investors in the periods of QE and compare these to the situation before and between phases of QE. If the (secondary) gilt market is a more attractive investment prospect as a result of QE then this should feed through to a lowering of the costs in the primary gilt market. By contrast, if QE activity creates or maintains pricing anomalies this could discourage investors and raise issuance costs. Thus, a key objective of our study is to assess whether QE led to beneficial side effects for either the investors in or issuers of gilts.

In meeting this objective, this study makes a number of contributions to our understanding of the effects of QE and of the functioning of the gilts market. While other studies have considered the immediate market reactions to QE activity, this study examines the behaviour of gilt returns and transactions costs over the fullness of the recent QE and non-QE phases. In addition, this paper is the first paper to analyse all three of the QE phases undertaken so far in the UK permitting comparisons to be drawn across the entirety of the QE exercise. Specifically, we partition our analysis into four sub-samples, a period prior to QE, the first phase of QE (QE1), the period between the end of QE1 and the start of the second phase, and the period of time since the start of the second phase (QE2) until two months after the end of the third phase (QE3).

We first examine the time series behaviour of gilt returns in each sub-sample to determine whether QE activity was generating any return behaviour that is indicative of market inefficiencies, and whether this could be associated with the phases of QE. We find that the QE1 period was characterized by the disappearance of significant first-order autocorrelation in returns, indicative of an improvement in pricing efficiency. By contrast, we find that in the periods following QE1 and including QE2 and QE3, the market displayed significant negative second and third-order correlation. However, simple market timing trading rules designed to exploit this autocorrelation could not generate profits in excess of transactions costs measured by the bid-ask spread, giving no reason to doubt the continued efficiency of the market. This result is further strengthened by the fact that bid-ask spreads themselves were reduced to around one-half of their pre-QE levels with the onset of the asset purchase programme and have remained at these lower levels in the more recent sub-samples.

The use of individual bonds returns enables us to clearly identify those effects of QE that are within the gilt market and those effects that may be between the gilt market and other financial markets. We explore the theoretical channels through which QE may affect the gilts market and in doing so provide a framework within which the results from analysing individual bonds can be used to distinguish within-market effects from cross-market effects. While the use of individual bonds has been a feature also of prior event studies, our study of the dynamics of individual gilt returns also enables us to contribute to the relatively sparse literature that has examined the effects of changes to the market structure and of major economic events on the return dynamics and efficiency of the UK bond market.[1]

Our most distinguishing contribution is to examine the effects of QE conditioned on the issuance activity that is happening around the purchase auctions. Previous studies that have mostly used an event study method have implicitly assumed that the event periods for each bond are not systematically influenced by other activity relating to the bonds. However, as we show, purchase auctions and bond issuance sometimes occurred on the same day and sometimes did not. We explore a regression based approach that permits the examination of multiple factors on the bond returns. Specifically, we examine whether the market is disrupted on the days of the asset purchases themselves. Using the regression framework, accommodating the observed autocorrelations and controls for other events, such as bond issuance and QE announcements, we find that gilts could generate a significantly large excess return on purchase auction days, whether or not they are the particular bond being purchased. On average this excess return is equivalent to a 50 percentage point return (above the mean return) on an annualized basis. What is striking is that this effect is almost identical through both QE sub-samples, suggesting that the asset purchases are having similar effects on the gilt market during later phases of QE as they had during QE1. Moreover, there is some

1. For example, Steeley (1992) examined the impact of the 1986 deregulation of UK financial markets on the dynamics of the gilts market, while Steeley and Ahmad (2001) examined the impacts of various changes to the microstructure of the market during the 1990s and the market's safe haven status during the Asian crisis and dot.com episodes.

evidence that a simple timing rule designed to capture this excess return would have earned profits in excess of the costs of transacting. This is some small suggestion that the pricing efficiency of the bond market is being disrupted by the activity of QE. We show that by the end of QE3, however, this pricing anomaly is no longer able to exceed transactions costs, indicating that the market had been able to eliminate the earlier disruption from QE purchase activity. This is in part due to the reduction in spreads over the phases of QE that we show is strongly related to the sustained presence of the Bank of England as a purchaser in the market. The fact that QE activity also reduced the bid-ask spreads in the market demonstrates an important trade-off between securing improvements to operational efficiency (costs of trading) and price efficiency (eliminating return anomalies).

Of course, economic policy makers might argue that it is entirely the intention of QE to distort the yields in the bond market, but we show that this is clearly not without side effects. If secondary market investors are able to make short-term excess returns during QE, then bonds may be being issued on less favourable terms (for longer-term investors) than would otherwise be the case. As the phases of QE were accompanied by much issuance activity, as part of a programme to recapitalize the banking sector, there were many occasions where issuance activity and QE purchase activity were taking place on the same day. It is possible, therefore, that bonds may not have been sold at as fair terms as would otherwise have been the case. This could generate reluctance on the part of longer-term investors to participate in gilt issuance auctions leading to a potential rise in the costs of debt issuance. Overall, our analysis shows that QE has had clearly identifiable side effects for the operational and price efficiency of the gilt market and that these have been mostly favourable. Any unfavourable effects appear to have been temporary experiences.

The remainder of the paper is structured as follows. The next section briefly reviews the UK QE operations, explores the economic theory that underpins the mechanisms through which QE can influence bond market efficiency and thereafter issuance costs, and reviews the prior related empirical evidence. Section 3 describes the data and some comparative summary statistics of the bond returns across the different QE-related sub-samples. Section 4 presents the analysis of the dynamics of gilt returns, trading costs and profits from autocorrelation based trading rules, for the same sub-samples. Section 5 reports the results of the regression analysis of the effects of gilt purchase auctions, controlling for other market activity. Section 6 describes the results of further trading rule tests designed to exploit the potential return anomalies relating to QE activity that are identified by the regression analysis. Section 7 considers the factors that affect trading costs during the phases of QE both to check that these are not confounding the return regression results, and also to determine what has caused their sustained reduction since the beginning of QE. Section 8 summarizes and concludes.

## 2. The Operation and Bond Market Effects of Quantitative Easing in the UK

The quantitative easing program in the U.K can be divided into three periods of activity. The first period, QE1, is between March 2009 and January 2010, when £200 billion was spent to purchase assets, mostly gilts. The majority of government bonds purchased was bonds with maturities of between 5 and 25 years. By the end of the first QE round 40% of the stock outstanding of 3-10 year maturity bonds were purchased, 50% of the 10-25 year maturity bonds, and 15% of the more than 25 years maturity bonds were purchased. Other assets such as commercial paper and corporate bonds were also purchased by the Bank but in significantly smaller quantities, and these were being sold back into the market by December 2009. At the meeting of the Monetary Policy Committee held on the 4th of February 2010, the members decided not to increase the limit for asset purchases further.

In October 2011 the second round of quantitative easing began (QE2) after the members of the Monetary Policy Committee voted to increase the limit of asset purchases further by £75 billion. A further increase of £50 billion was announced in February 2012 and the purchases were accomplished by the 2nd of May 2012. Thus, the second round of QE program can be characterized by £125 billion of asset purchases between October 2011 and May 2012. After only a two-month gap the QE asset purchase facility was restarted again. On the 5th of July 2012, the MPC announced a further £50 billion of gilt purchases, to be completed by November 2012, QE3. Although the QE2 and QE3 phases have been separately distinguished in some recent survey papers, Joyce et al (2012) and Martin and Milas (2012), the short gap between them may mean that this distinction is not preserved in the future. To obtain comparable sample sizes for QE and non-QE phases in this study, we choose not to distinguish between the QE2 and QE3 phases.

## 2.1 The effects and side-effects of QE: Theoretical considerations

Quantitative easing has three main channels through which it can affect the economy. The first is a signaling channel. The use of QE demonstrates a commitment to low interest rates and monetary easing more generally, and this is likely to boost investment and consumption. The second is a liquidity channel. In this case, the purchases of gilts from the banks, by the Bank of England, enhance their reserve levels, that should then facilitate greater lending to commercial activity. The third channel is a portfolio balance channel, whereby the purchases of gilts may lead to an increase in asset prices, which leads to both wealth effects and lower costs of capital, that in turn boosts the economy through increased investment and consumption. As well as the direct upward pressure on gilt prices that may arise from the Bank's purchases, there can arise an additional "ripple effect" to increase the prices of other assets if the sellers of the gilts do not regard the cash received as a perfect substitute for the gilts sold, and use the cash to purchase other assets. This process may continue until all asset prices have been bid upwards to rebalance asset portfolios to accommodate the increased cash balances.[2]

The nature of the portfolio balance channel was originally described by Tobin (1961, 1963, 1969) and Brunner and Meltzer (1973). They argued that central banks, by varying the relative supplies of assets with different maturities and liquidity, could affect the relative yields on those assets due to imperfect substitutability. Thus, following an asset supply shock, relative prices and yields would adjust to restore equilibrium. The preferred habitat and segmentation theories of Culbertson (1957) and Modigliani and Sutch (1966), where investors have preference for a particular range of maturities along the yield curve, implies that an imperfect substitutability may exist also within the bond market itself.

While these theories generate useful comparative static predictions of the possible effects of QE on yields, they do not directly address the possible effects on the return dynamics and trading costs that are the focus of this study. However, in combination with the theoretical results in Ross (1989) a possible transmission mechanism from QE actions to return dynamics can be developed. Ross (1989) used a no-arbitrage martingale theoretical asset pricing framework to establish that the magnitude of price changes reflects the rate of information flow into an efficient market. If the market is absorbing information too slowly, then price adjustments may be too small, and successive price movements are likely to be

2. See Benford et al (2009) for more detail on how each of these QE transmission channels operates.

positively correlated. By contrast, if the market is overreacting to information, then price adjustments may be too large, generating negative autocorrelation until the genuine signal within the information is deciphered. Thus, if market participants display differential speeds of processing the implications of QE activity, then this can generate dynamic regularities in bond returns. As the QE purchase auctions were unprecedented events, it would not be surprising if market participants had difficulty initially in processing the implications of these events, at least temporarily.[3]

In addition to the effects on return dynamics, the presence of the Bank of England as a large buyer may improve the functioning of the gilt market, making it easier for participants to sell gilts, particularly during stressed conditions. Together the transactions costs and inventory-based theoretical models of market microstructure would suggest that the increasing market activity would reduce the likelihood of gilt traders holding undesirable inventory positions, which in turn would reduce the spreads that are the compensation for providing immediacy in transactions.[4] By the end of QE1, for example, the Bank of England owned as much as 60 percent of the outstanding stock of some gilts, with an average ownership across the market of around 30 percent. The ownership of gilts by the Bank of England across the sample is shown in Figures 1 and 2. Average ownership increased between QE1 and the later QE phases, but not significantly ($p=0.18$), while the ownership shares during the phases of QE are significantly higher than for the period in between ($p<0.01$). This dip in ownership share between the phases of QE, in Figure 1, is a result of the issuance activity increasing while QE was paused. This increase in issuance can be seen in Figure 2. The extensive participation by the Bank of England in the market should improve liquidity and, in turn, reduce the bid-ask spreads. These reductions in spreads may also feed through to reductions in (positive) return autocorrelation. If transactions costs fall, then smaller price anomalies can be traded upon profitably. If prices are adjusting too slowly, because transactions costs are prohibiting a more timely adjustment, then the lowering of transactions costs should deliver an increase in the speed of price adjustment. This should reduce positive autocorrelation in returns.

3. The possibility of differential speeds of information processing is a key feature of behavioral explanations of asset pricing behaviour, see, for example, Barberis et al (1998). The role of informational asymmetries (in knowledge as opposed to processing ability) in generating protracted effects on asset prices, and bid-ask spreads, is a key feature of models of financial market microstructure, going back to Bagehot (pseud. Treynor) (1971), Copeland and Galai (1983), Glosten and Milgrom (1985) and Kyle (1985).
4. The role of transactions costs in the determination of spreads was first formalized by Demsetz (1968). Early inventory based models of market microstructure include Garman (1976), Amihud and Mendelson (1980) and Ho and Stoll (1980).

Since an efficient financial market provides a fair price for both investors and issuers, the removal of sluggish or exuberant price adjustments is likely to be beneficial to both types of participant, if this encourages greater participation in the market that improves liquidity and further drives down spreads in a virtuous circle.

Moreover, if the market itself becomes more attractive to investors relative to other assets, as result of the removal of pricing anomalies and the reduction in spreads, then this could raise the demand for gilts still further and lead to a lowering of the financing costs for the Treasury; a beneficial side effect of QE. By contrast, if QE has generated pricing anomalies or increased spreads, against what might be expected given the discussion earlier in this section, then the gilt market might be a less attractive long-term investment prospect and so issuance costs may rise. Issuance costs may also rise if there is a contemporaneous over-supply of gilts into the market, which would decrease prices and increase yields. Such a situation presents a potentially destabilizing scenario of issuing debt to fund the QE programme, rather than to meet the fiscal deficit.

Since QE coincided with a huge fiscal deficit brought about by the need to recapitalize the UK banking sector, there was a huge net issuance of gilts during the QE period. This can be seen in Figure 2 that shows the expansion of the gilt market on a monthly basis from 2004 until 2013, the cumulative net issuance (expansion of the total debt) to that month, and the proportion of the total stock owned by the Bank of England by that month. Because of this extensive issuance activity, which ran alongside QE and with it was ultimately part of the broader economic policy measures being adopted in the post-crisis period, it becomes an empirical question as to whether the phases of QE led to a fall or an increase in yields, and thus the cost of government debt issuance. This is also the reason for controlling for issuance activity in the analysis of return behaviour in response to QE activity.

With the Bank of England having independence to decide the stance of UK monetary policy, the Treasury effectively has to accept whatever are the consequences of QE activity for the costs and risks of debt issuance of QE activity. While it is in the broader economic interests that QE does not raise the costs of debt issuance, the Treasury may have been willing to accept any (temporary) rise in the costs of debt issuance if this ensures the credibility of the Bank of England’s monetary policy.

## 2.2 Prior empirical findings of the effects of QE

Using an event study method, Meier (2009) finds that the first round of QE purchases reduced the 10-year yield on gilts by at least 35 to 60 basis points. Joyce et al (2011) find that gilt yields were reduced by as much as 100 basis points by the purchases. However, studies by both Glick and Leduc (2011) and Meaning and Zhu (2011) find considerably smaller effects closer to 50 basis points.[5] This difference may reflect the different choices of event windows between the studies. Glick and Leduc (2012) and Meaning and Zhu (2011) use a single day event window, whereas Joyce et al (2011) use a two day window. Doubling the event window appears to double the reduction in yields.

Joyce and Tong (2012) use high-frequency data to examine the effects of announcements of QE activity, such as decisions to raise the threshold, and also the purchase auctions on the yields of individual gilts. Their evidence suggests that the key QE announcements also reduced yields by around 100 basis points on these days. They also identify local supply effects of gilt purchase auctions, whereby the yields of gilts fall temporarily in response to the quantity of gilts issued and also to those of near maturity substitutes. The yields also responded after the auction to the amount of information that the auction itself conveyed about the supply of gilts.

Breedon et al (2012) examine the impact of QE1 on the UK bond market by using a macro-finance model to construct a counter-factual yield curve. By comparing the difference between the observed yield curve and their estimate of what the yield curve would have been in the absence of QE, they too find a reduction in yields resulting from QE of around 50 basis points at the 10 year maturity.[6]

There are relatively fewer studies considering the QE2 and QE3 periods. Joyce at al (2012) found that yields actually rose slightly during QE2, but only by amounts well within the margins of international yield movements around the same period. Meaning and Zhu (2011) also suggest that QE2 did not reduce government bond yields. However, a study Banerjee et al (2012) that used changes in auction maturity sectors to assist in the

5. However, Glick and Leduc (2012) report stronger effects of asset purchases on US bond yields of around 100 basis points for the 10 year maturity. Other studies of the effects on US bond yields, which encompass a range of movements of between 30 and 100 basis points, include Gagnon et al (2011), D’Amico and King (2010), Doh (2010), Krishnamurthy and Vissing-Jorgensen (2011) and Neely (2012).
6. Other models of the yield curve have been used to examine the impact of US QE by, for example, Hamilton and Wu (2011) who found a 13 basis point yield reduction for US QE2 and Bauer and Rudebusch (2013) who found an 89 basis point reduction in the 10 year yield for QE1.

identification of supply surprises indicates that the effects of QE2 were of similar sign and magnitude to those of QE1. Some preliminary event study analysis in Martin and Milas (2012) undertaken while QE3 was still in progress indicated that yields fell at most by 12 basis points.

In summary, the existing evidence suggests that QE asset purchases engineer short-lived changes in bond yields. This is broadly consistent with the successful operation of a portfolio balance transmission mechanism through to the wider economy.[7] Only a portion of the existing empirical work considers individual bonds, with much looking at the yield curve that may obscure some of the finer detail. The objective in this study is to not only focus on individual bonds, but to do so from the viewpoint of whether there are beneficial or detrimental side effects from QE activity, which are either concealed within previously observed effects on yields or are in addition to these effects.

## 3. Data and Summary Statistics

We use a sample of 46 UK government bonds that collectively span the period January 1st, 2004 to May 10th, 2013. This is a period of 2362 trading days. The bonds selected comprise all the conventional style gilts that had at least 2 years of data available during the sample period and a maturity of at least three years. The three years to maturity limit ensures that each bond both meets the two years of data requirement and is not affected by a "pull-to-par" effect on price as the bond approaches maturity.

We divide the sample period into four sub-periods to provide comparative statistics for periods before, during and between episodes of quantitative easing. Sub-period A, which runs from January 1st, 2004 to March 10th, 2009 is a pre-QE sub-period. Sub-period B, which runs from March 11th 2009 to January 26th, 2010, spans the first round of the QE programme (QE1). Sub-period C, which runs from January 27th 2010 to October 7th, 2011, is the period between the first and second rounds of QE. Sub-period D, which runs from October 10th, 2011 to May 13th 2013, contains the second and third rounds of QE (QE2 and QE3) and the short interval between them.[8]

7. Studies of the wider economic impacts of QE in the US and UK include Baumeister and Benati (2010), Lenza et al (2010), Kapetanios et al (2012), Chung at al (2012), Bridges and Thomas (2012) and Lyonnnet and Werner (2012).
8. To facilitate some out-of-sample tests, in Section 6 below, we also sub-divide the QE2&3 period, to use the QE3 phase as an out-of-sample test period relative to QE2.

The set of 46 bonds in the sample is shown in Table 1 and represents a range of maturities in the market from 3 years out to the year 2060. The coverage across each of the four sub-periods, which is shown in the table, depends on the maturity of the bond and when it was issued. There are 17 bonds that are included in all four sub-periods.

We analyze the statistical properties of returns calculated from the log daily change in the closing clean price. This data are collected from Datastream. Detailed summary statistics of the returns are contained in Table A.1, in the Appendix, which is divided into four sections corresponding to the four sub-sample periods. Box plots in Figures 3 and 4 summarize the (annualized) mean and standard deviation properties of the returns across the set of bonds in each sub-sample. The impact on the mean returns of the market entering the first phase of QE is dramatic, with a fall from a median (of the cross section of mean returns) of 1.4 percent per year (excluding coupon income) before QE to a median returns of -5.5 percent per year (excluding coupon income) during the first phase of QE. In the post QE1 period, the median return exceeded 8 percent per year, which suggests that the ending of the first phase of QE was seen good news for the bond market. During the second and third phases of QE, the median return was little different to its level prior to the first QE period, at 1.6 percent per year. However, the box plots in Figure 5 show that the distribution of mean returns was more negatively skewed during this latter period. Mean returns in each of the four sub-periods are statistically significantly different from each other ($p<0.01$) in all cases except for the QE2&3 phase, which is not significantly different from the Pre-QE1 phase ($p=0.26$).

By contrast to the behavior of the mean returns, the standard deviation of returns increased when the gilt market entered the first phase of QE. This increase is statistically significant, ($p=0.052$). The median annualized standard deviation of returns prior to QE1 was 5.1 percent per year. This increased to 7.9 percent during the QE1 phase. Post-QE1, the volatility in the market has remained higher than its pre-QE levels, at around 7 percent per year. The skewness of returns also changes upon entering the first phase of QE. The median skewness is negative during this period but is positive both before QE1 and afterwards. The skewness statistics for the individual bonds in Table A.1 show that the skewness change has a regularity related to maturity. Prior to QE, short term bonds appeared negatively skewed, while longer term bonds were positively skewed. During QE1, all bonds exhibit a negative skew in their returns. After QE1, but before QE2, the skew in returns changes sign for all but three of the bonds. During QE2 and QE3, the skewness in returns remains positive for shorter term bonds but becomes negative for longer term bonds. The excess kurtosis for the bond returns is also related to maturity, but is not obviously responding to the phases of QE. The shorter term bonds have the highest kurtosis and this reflects the relatively high proportion of zero returns that these bonds exhibit as their volatility diminishes as they get closer to maturity. Although the three-year cut-off for inclusion in the sample is designed to remove pull-to-par effects, it is clear that some remain in the few shortest bonds in each of the sub-sample periods.

# 4. Empirical Analysis of Bond Returns

## 4.1 Return Autocorrelation

A sufficient condition for an efficient securities market is that prices behave randomly, and so the analysis of the impact of QE on the returns in the Gilt market begins with an examination of their autocorrelation properties. We consider two statistics that capture the relationship between successive returns, the autocorrelation coefficient and the variance ratio. Evidence against the null hypothesis that returns are randomly generated is provided by evidence of statistically significant non-zero autocorrelations in the daily returns series. Autocorrelations of daily returns can be calculated from the sample autocorrelation function

$$AC(\tau) = \frac{\sum_{t=1}^{T-\tau}(r_t - \bar{r})(r_{t+\tau} - \bar{r})}{\sum_{t=1}^{T-\tau}(r_t - \bar{r})^2} \qquad (1)$$

where $r_t = \ln(p_t/p_{t-1})$ are the log daily returns calculated from clean prices, $p_t$; the mean return is $\bar{r}$; $\tau$ is the lag in days; and $T$ is the sample size. Under the null hypothesis of random (and normally distributed) variables, approximately $\sqrt{T}AC(\tau)\sim N(0,1)$. For the pre-QE sub-sample, this means that autocorrelation coefficients in excess of 5.5 percent are likely to be significant, unless bonds have shorter sample periods due to being issued or redeemed during this period. Similarly, the approximate critical values are 13.2 percent, 9.5 percent and 9.8 percent for the QE1 sub-sample, the post-QE1 sub-sample and the QE2&3 sub-sample, respectively. The autocorrelation coefficients can also be collectively, and cumulatively, analysed using the Ljung-Box (1978) statistic, which is calculated as

$$Q(m) = T(T+2)\sum_{\tau=1}^{m}(T-\tau)^{-1}AC^2(\tau) \tag{2}$$

and is distributed $\chi_m^2$.

For random returns, the variance of returns measured across ever longer horizons increases linearly with that horizon period. For example, the variance of returns measured across two days should be double the variance of returns measured across a single day. Thus departures of the following variance ratio statistic from unity provide evidence of non-random behavior. In particular, the variance ratio statistic, *VR*(2), that compares one and two day return variances is given by

$$VR(2) = \frac{\mathrm{Var}[r_t(2)]}{2\mathrm{Var}[r_t]} \tag{3}$$

where $r_t(2) = r_t + r_{t+1}$ is the two day return. The use of long horizons returns, such as in variance ratio statistics, reduces the number of observations unless overlapping returns are considered. Lo and MacKinlay (1988, p.50) derive a test statistic and sampling distribution for a variance ratio using overlapping observations, and further refine the sampling distribution to accommodate heteroscedasticity (changing variance) in the returns.[9] This statistic, denoted *LMhet*, is distributed standard normal and so departures from randomness are given by absolute values of the statistic in excess of 1.96.

The autocorrelation and variance ratio statistics, for each bond in each of the four sub-samples, are given in Table A.2 in the appendix. Figures 6-8 summarize the autocorrelation statistics across the bonds in each sub-sample, for the first three lags, using box plots. Most of the bonds during the pre-QE period display significant first order autocorrelation. This result is confirmed by the variance ratio tests. This autocorrelation is slightly larger for shorter term bonds than medium term bonds, which may reflect a residual pull-to par effect in the shorter term bonds. The QE1 period is remarkable for having no significant autocorrelation. The post-QE1 period has significant negative second order autocorrelation among the medium

9. This sampling distribution exploits the result that the variance ratio for q-horizon returns is a linear combination of the first q-1 autocorrelation coefficients, and that the variance of autocorrelations can be computed given some relatively weak additional assumptions, see Lo and MacKinlay (1988, p.49), and also Taylor (1986, p.116-121).

and longer term bonds, while almost all of the bonds in the QE2&3 period have significant negative third order autocorrelation.

At first glance, these contrasting autocorrelation statistics indicate that during the QE1 period, the gilt-edged market was closer to an efficient market than it had been prior to this or has been subsequently. The elimination of this autocorrelation following the commencement of QE is consistent with the presence of the Bank of England in the market driving down the spreads. This reduction in the cost of trading served to encourage trading that acts to eliminate the sluggish price adjustment that generated the autocorrelation. However, while the absence of autocorrelation is consistent with market efficiency, the presence of autocorrelation does not necessarily imply inefficiency. Unless the observed autocorrelations can be exploited for profit, the market cannot be regarded as inefficient. Before turning to this specific issue, we also consider whether there are regular events in the gilt-edged market that could give rise to the observed patterns in the daily returns. In particular, we examine the pattern of issuance and QE-related purchase auctions, across days of the week. Gilts were issued regularly throughout the sample, and with increasing frequency in the more recent three sub-samples, to fund the deteriorating fiscal economic position in the UK. During the phases of QE, bonds were being purchased by the Bank of England, on a pre-announced timetable.

The details of the purchase auctions were announced at 4pm on the Thursday prior to the week of the auctions. The maturity ranges of bonds, the size and timings of the issues were little changed from week to week, and so auction participants had a fair degree of certainty as to which gilts would be being purchased by the Bank of England several weeks ahead of the Thursday announcements.

The pattern of issuance and purchase auction days can be seen in Figures 9 and 10. Gilts are issued mostly on Wednesday, Thursday and Friday, with relatively more on Wednesdays or Fridays. The purchase auctions during the phases of QE were mostly on Mondays, Tuesdays and Wednesdays, with relatively more on Mondays and Wednesdays during the QE1 period. The activity during the QE1 phase is particularly high, with almost half of the Wednesdays experiencing bond issuance and around four fifths of the Wednesdays experiencing purchase auctions. They key observation is that the patterns of either issuance or purchase auctions are similar across the four sub-samples, suggesting that neither issuance patterns nor purchase auction patterns are strong contenders to explain the autocorrelations observed in the market. The lack of a strong economic rationale for the autocorrelations perhaps indicates that they are unlikely to be able to be exploited for economic profit. They may have simply been within the limits of price anomalies that can be sustained within the magnitudes of transactions costs. We now turn directly to the issue of whether these anomalies could have been exploited for profit.

## 4.2 Autocorrelation based trading rule tests

In this section we describe some simple trading rules that can be used to determine whether the significant autocorrelations observed in the gilt market could have been exploited, to produce returns in excess of a buy-and-hold (passive) strategy or a risk-free investment. The rules are simple timing rules that exploit the momentum or reversion in returns identified by the autocorrelation.

For significant positive first lag autocorrelation (persistence), the following is an appropriate "active" trading strategy. It involves investing in the gilt over the current day if the return of that gilt was positive during the previous day, and liquidating the position (and investing in cash or a risk-free asset) if the gilt return was negative during the previous day. The end of sample value of $1 invested in this strategy over the entire sample period is given by,

$$J_T(\text{Active}) = e^{\sum_{t=1}^{T} \alpha_t r_t + (1-\alpha_t) rf_t} \tag{4}$$

where, $rf_t$, is the risk-free rate, and the timing variable $\alpha_t$ is given by

$$\alpha_t = \begin{Bmatrix} 1 & \text{if } r_{t-1} > 0 \\ 0 & \text{if } r_{t-1} < 0 \\ \alpha_{t-1} & \text{if } r_{t-1} = 0 \end{Bmatrix} \tag{5}$$

This terminal wealth can be compared to that from a passive investment in the same portfolio, and also in the risk-free asset, that is,

$$J_T(\text{Passive}) = e^{\sum_{t=1}^{T} r_t} \tag{6}$$

$$J_T(\text{Risk-free}) = e^{\sum_{t=1}^{T} rf_t} \tag{7}$$

This rule does however generate a high trading frequency among the gilts, and trading costs (even just the bid-ask spread) may make the rule unprofitable. The percentage deduction from the daily returns that equates the terminal values of the active and static investment strategies can be viewed as an upper bound on the costs that can be incurred by the active investment rule to leave it with a return greater than the static rule. Specifically, this break-even cost is given by $c$, where

$$c = \frac{\ln\big(J_T(\text{Active})\big) - \ln\big(J_T(\text{Passive})\big)}{s} \tag{8}$$

where $s$ is the number of one-way trades within the sample period.

The timing rule as described above exploits momentum, that is, positive autocorrelation in returns. It is relatively simple to redesign the rules to exploit negative autocorrelation, mean reversion. For example, for negative third order autocorrelation, the timing variable, $\alpha_t$, becomes

$$\alpha_t = \begin{Bmatrix} 0 & \text{if } r_{t-3} > 0 \\ 1 & \text{if } r_{t-3} < 0 \\ \alpha_{t-1} & \text{if } r_{t-3} = 0 \end{Bmatrix} \tag{9}$$

so that positive [negative] return signals a sell [buy] order ahead of the return 3 periods later. The timing variable for negative second order autocorrelation is constructed similarly, but using returns with a two period lag.

The results of the application of the trading rules are summarized in Table 2, while the distribution of payoffs across all the gilts in each sub-sample can be seen in Figure 11. The left side of the table shows the results for the pre-QE period, when the market was characterized by positive first lag autocorrelation. An immediate implication of the trading rule tests is that, on average, investment in gilts produced a small capital gain, of around 5 percent, over this 5 year period. The active timing rule beat the passive strategy in 16 of the 31 cases, but was not significantly better than undertaking a risk-free investment over the period ($p=0.127$). By partitioning the set of bonds between those that exhibited significant autocorrelation, upon which the timing rule was base, and those that did not, it is possible to generate an "out-of-sample" subset of bonds with which to make some additional comparisons. If the timing rule works as well "out of sample" then this is stronger evidence against an efficient market. In this case, there is no significant difference between the active trading strategy for each subset of bonds ($p=0.364$). So, while there was significant positive autocorrelation in the bond market ahead of the QE period, this does not seem to generate performance in excess of a risk-free deposit rate.

The middle panel of the table shows the results for the post QE1 period, when the market was characterized by negative second order autocorrelation, in particular among the medium to longer term bonds. In this case, the active strategy has significantly greater performance than the passive strategy ($p<0.001$), and the passive strategy is significantly higher performing than a risk-free deposit. For 22 of the 30 bonds, the active strategy outperforms the passive strategy, with a mean difference across all bonds of 5.35 percent over this 21 month period. The active strategy is significantly better for the bonds that exhibited significant autocorrelation ($p<0.001$), with the in-sample bonds generating a return of almost 29 percent on average over the 21 months compared to a return of just 8 percent for those without significant autocorrelation, where the return did not significantly exceed that of the passive strategy. This result validates the timing rule as an appropriate vehicle to exploit the observed autocorrelation.

The right side panel of Table 2 considers the period during which the QE2 and QE3 episodes took place, and when negative third order autocorrelation was observed in the majority of the bonds' returns series. In this case also, the active strategy produced an average return in excess of the passive strategy, of around 9 percent over the 20 month period, ($p<0.001$). Twenty four of the thirty one bonds exhibited an active strategy that was greater than the maximum of the risk-free rate or the passive strategy. The performance of the in-sample bonds was significantly better than that for the out-of-sample bonds, ($p<0.001$), and the out-of-sample bonds both underperformed a risk-free deposit.

Overall, there is evidence that in the post QE1 periods, gilts exhibiting strongly significant negative autocorrelation of second or third order can be exploited to produce returns in excess of buy-and-hold returns. However, the timing rules to generate these returns require very frequent trading, at close to every other day in most cases. From equation (8), the per one-way trade, break even transactions costs range from 1 to 11 basis points, with the values increasing in the maturity of the bond. Figure 12 shows the range of bid-ask spreads observed for the bonds in each of the sub-samples. The spreads are computed from the close of day bid and ask prices available on the Thomson Eikon platform, and averaged across the sub-sample. The box plots in Figure 12 present the distribution of these average spreads across the range of bonds in the sub-sample. In the two sub-periods where the bonds with significant autocorrelation produced returns using an active timing strategy that exceed that of a passive strategy, the median bid-ask spread is around 6 basis points, with an inter-quartile range of between around 3 and 10 basis points. In the post QE1 period, only three bonds had break-even transactions cost levels exceeding 6 basis points, and in the QE2&3 period, only 8 of the bonds had break-even cost levels that exceeded median spreads. Since these bonds are those of longer maturity and the spread data also indicate that spreads increase with maturity, it appears very unlikely that excess profits could be generated from exploiting the negative autocorrelation in bond returns arising since the end of the first phase of QE.[10]

The spread data in Figure 12 also indicates that the increased market activity associated with QE has reduced average spreads in the gilt market by around 5 basis points. The difference between average spreads (using either the mean or the median) is statistically lower by the end of the phases of QE than it was prior to QE1 ($p<0.04$). This is a clear improvement in the operational efficiency of the market arising from the lowering of spreads.

10. Joyce et al (2012) using data for just the QE1 period also find that gilt spreads increase with maturity. Their average spreads, which are measured only on days of purchase auctions, are around 2-3 basis points lower than that we observed across all trading days in this period.

This also acts to improve pricing efficiency, since it means that otherwise unprofitable pricing anomalies can now be traded away.

So, even if an investor had correctly guessed that these trading rules would work during the different sub-samples, there is no indication that they would have made excess returns after taking into account transactions costs. Thus these apparent changes in the dynamics of bond returns across the phases of QE are within the limits of what can be sustained by the levels of transactions costs. While the broad return patterns arising after the end of the QE1 period are not suggestive of any deterioration in market efficiency and, indeed, the reduction in spreads indicates some enhancement, it is possible that the regular market events themselves, such as issuance or purchase auctions, could affect the market. We turn now to this question.

## 5. Regression tests of the effects of bond market events

While the distribution of issuance and purchases across days of the week, shown in Figures 9 and 10, did not seem likely to generate the autocorrelations observed in the daily returns data, it is still possible that these days may provide individual opportunity to earn excess returns. Short run excess returns to investors imply that bonds may not be being issued on a fair basis. This could have negative reputational effects that could raise the costs of issuance if longer term investors fear that they are receiving unfairly low yields.

To examine this possibility, we use a regression based analysis. While previous studies have considered an event study approach to examining the effects of purchase auctions, for example, Joyce et al (2011) and Meaning and Zhu (2011), the dependence of their results on the event window length suggests that there is value in examining other approaches. The regression approach that we adopt also has the advantage of permitting multiple factors to be considered simultaneously, in particular issuance activity. The previous event studies implicitly assume that the characteristics of the event windows are constant across bonds, whereas some bonds may have experienced issuance within the event window while others may not have had this happen.

We estimate the parameters of the following regression equation for each bond in each of the four sub-sample periods.

$$r_t = b_0 + b_1 r_{t-1} + b_2 r_{t-2} + b_3 r_{t-3} + b_4 r_{t-4} + b_5 r_{t-5} + b_6 OI_t + b_7 IS_t + b_8 OP_t + b_9 PS_t + b_{10} PA_t + b_{11} SH_t + b_{12} QEA_t + b_{13} MPC_t + b_{14} BR_t \tag{10}$$

where $r_t$ is the return to a bond on day *t*, and the lagged values as explanatory variables are to control for the effects of the autocorrelations examined in the previous sections of the paper. All but one of the remaining variables are event indicator variables, taking the value 1 if the event occurs and zero otherwise. The variable $IS_t$ indicates days on which bonds were issued into the market, either new issues or secondary offerings. The variable $OI_t$ indicates the days on which this particular bond had issuance activity. The advantage of using the regression based approach is that it is possible to include these controls for issuance activity within the examination of the effects of QE related events. Figures 9 and 10 show that during the QE1 phase more than 45 percent of Wednesdays featured new issues of gilts. Asset purchases occurred on over 80 percent of the Wednesdays during the same period. By contrast, a similar intensity of asset purchases on Mondays was not accompanied by any issuance activity. The issuance indicator variables are used to control for this heterogeneity. We use variables that indicate both issuance specific to that bond and also of issuance in general. Price effects of specific bond issuance have been discovered previously in studies of gilt issuance auctions by Breedon and Ganley (2000) and Ahmad and Steeley (2008), which document a price fall response on auction days, which could be exploited for profit, together with some evidence that this is anticipated. We expect this variable to display a negative sign. The general issuance indicator variable is used to capture any general disruptive market impacts from issuance, and can also provide evidence of whether bond prices are influenced by supply changes of other bonds, as would be required in a portfolio balance transmission channel. The sign of this variable could be positive or negative depending upon the segmentation of the market and the signals generated by the issuance activity. If issuance is seen as a signal of continuing fiscal deterioration, then any issuance could reduce bond prices. If the market is highly segmented, then issuance of other bonds could raise the (relative) price of other bonds. If the market is not at all segmented, then issuance is also likely to reduce the prices of bonds, which all appear to be close substitutes.[11]

11. In an earlier draft of this paper, a variable was included to indicate whether issuance was by syndication rather than auction. Syndication as an issuance method was re-activated during the financial crisis to "facilitate the primary market distribution of long-dated conventional and index-linked gilts … (to) better to align supply with demand for such securities from key investor groups" (DMO, 2009, p.27). Syndication was used on just eleven days within the 286 days on which bonds were issued during the full sample of 2362 days. As the variable was not significant for any bond, it has now been removed from the specification of equation (10).

The possibility of capturing the operation of a portfolio balance channel specifically within the QE asset purchase activity is achieved by distinguishing three types of purchase activity among the indicator variables. The variable $PA_t$ indicates the days on which any bonds were purchased (by reverse auction) through the Asset Purchase Facility (APF) mechanism of QE. The variable $OP_t$ indicates the days on which this particular bond was being purchased through the APF mechanism. The variable $PS_t$ indicates days on which a close substitute bond was being purchased by the Bank of England. We define a close substitute bond to be one within the same official maturity segment of the market. These are defined as ultra-short term (0-3 years), short-term (3-7 years), medium term (7-15 years), long term (15 years and beyond).[12] The variable $OP_t$ is designed to capture the specific price effects of QE purchases. This specific increase in the demand for a gilt from the Bank of England is expected to raise the gilt price, as has been documented in the event studies of QE. If the bonds classified as close substitutes are indeed close substitutes, then we would expect the bond price to rise on their purchases, that is, for the coefficient on $PS_t$ to be positive. When the Bank of England purchases particular bonds, a portfolio balance effect within the bond market would suggest that the cash received for the bonds would be spent on substitute bonds, so increasing their price also. If they are not close substitutes, such that the market is even more finely segmented than the official maturity ranges might imply, then we would not expect a price response. If general purchase activity (not specifically of that bond or a close substitute) raises the price of the bond, this suggests that gilts are collectively seen as close substitutes and that the market is not at all segmented. This would also imply that portfolio balance effects are working more strongly across asset classes, than within the gilts market. Using the different purchase indicators in this way, therefore, enables us to identify where portfolio balance effects are most likely to be working.

The variable $QEA_t$ indicates the days of major policy announcements relating to QE, such as the starts and ends of phases, and adjustments to the limits of the bond purchases. The announcements are summarized in Table 3. Joyce and Tong (2012) have distinguished between QE related announcements and the actual APF auction activity in their event studies and find that both have a positive effect on price. By including an announcement indicator variable, we can control for these effects during the examination of the effects of the

12. This approach to defining substitutability follows D'Amico and King (2010).

purchases, which was not possible in the event study framework. The variable $MPC_t$ indicates those days on which a meeting of the UK's Monetary Policy Committee (MPC) made its monthly announcements. The variable $BR_t$ indicates those days (only in the pre-QE period) on which the MPC changed the base interest rate. These variables enable us to distinguish between the announcements of the MPC in general (conventional monetary policy announcements), specific conventional monetary policy changes, $BR_t$, announcements relating to unconventional monetary policy, $QEA_t$, and specific unconventional monetary policy actions (the purchase indicator variables discussed above).

The variable $SH_t$ measures the share of the gilt that is in the ownership of the Bank of England. Figure 1 shows that these ownership shares vary from under 10 percent to over 60 percent and so controlling for these very substantial differences in the free float of individual gilts when examining the effects of QE activity seems prudent.[13]

The results from estimating equation (10) are given in Table 4. During the pre-QE1 sub-sample, Panel A of the table, there is evidence that on days of general issuance and on days that the MPC held its monthly meetings, the returns to gilts significantly exceeded their average across the sub-sample. To gauge the economic significance of this, we calculate the annualized excess return (above the sub-sample average return) implied by these significant indicator regression coefficients. On issuance days, the annualized return is over 30 percentage points more than it is during the sub-sample as a whole, while on MPC days, the annualized excess return is almost 20 percentage points. These are both significantly above the average return ($p<0.01$). Neither own issuance activity nor base rate changes appeared to influence returns in this pre-QE1 period. This suggests that both were already factored into the gilt returns.

During the QE1 period, reported in Panel B of Table 4, there are significant event indicators for the days on which a particular bond itself experienced further issues or APF activity, but the signs of the coefficients on these variables are mixed, which does not suggest the presence of an empirical regularity. There are seven long term bonds that exhibit significant negative coefficients on the indicator for the purchase activity in a substitute bond. This would indicate a high degree of segmentation within the long term bonds. Within other

13. Joyce and Tong (2012) also control for the size of the free float in their analysis. In a previous draft, we had included a variable that measured the excess of purchase activity over issuance activity within a month. While similar in spirit, using the ownership share variable instead provides a more tightly defined and higher frequency measure.

maturity ranges, there is little evidence of an effect from the purchases of close-by maturity bonds. This suggests that portfolio balance mechanisms may struggle to operate within a maturity range, but may have more success across maturity ranges within the gilts market. Within the QE1 period, the most consistent effect appears to be for the set of medium to long term bonds for which APF activity in general appears to generate a significant increase above the average return. The regression coefficient is equivalent to an annualized excess returns averaging 38 percentage points. This strong effect of general purchase activity is further evidence that portfolio balance channels may have more success across asset classes rather than within the gilts market itself.

In the post QE1 period, Panel C of Table 4, there are a few bonds that exhibit significant different returns on days of own issuance, but again the signs are mixed. One bond's returns responded significantly to QE announcement days, but this is within the bounds of chance. Overall, in this period between the end of QE1 and the start of QE2, there is no evidence of significant distortions occurring to gilt returns.

The QE2&3 sub-sample, reported in Panel D of Table 4, shows that issuance activity of any kind is either well anticipated by the market or quickly absorbed into prices well within the trading day. As was seen in the QE1 period, there is a group of medium to long term bonds that are responding positively to days of APF activity in general, again supporting the possibility of a portfolio balance channel across asset classes. While there are some counter examples, a group of long term bonds display a strong positive relationship between their return and the purchase of substitutes. This is evidence that the portfolio balance mechanism might have more opportunities within the QE2&3 phase than it had during QE1, with long term bonds appearing to be substitutable.

From across all of the sub-samples from the beginning of QE1, we also note that the share of gilts owned by the Bank of England does not appear to be influencing returns nor do further announcements by the MPC either in regards to QE or of the results of their monthly meetings.

## 6. Trading rule tests of bond market event effects

While the regression analysis can provide evidence as to which QE related factors appear to be driving returns and, as expected we find that purchase activity raises prices, it cannot directly tell us whether these responses in returns represent anomalous pricing. Such anomalous pricing could then indicate that QE activity was disrupting the efficiency of the market, that in turn might affect issuance costs. The implied annualized returns on certain event days, which were found to be substantially above the average return for the particular sub-sample are indicative of possible excess returns, but an analysis of trading rule profits and transactions costs is again necessary to establish evidence of inefficiency.

In this section, we examine the profits from simple timing rules designed to respond to the market events, where the regression coefficients are suggestive of anomalous pricing. The timing rules work in exactly the same manner as for the autocorrelation based analysis, except that now the rule requires the gilt to be bought (or sold, if the indicator variable regression coefficient is significantly negative) at the end of the day prior to the event day and sold at the end of the event day. Of the event days, only the QE announcements and base rate changes are of unpredictable timing and as neither of these generated any significant effects, with the exception of two bonds in the most recent two sub-samples, the event days that we analyse can be considered as known in advance, permitting the operation of the timing rule.

The results of this timing rule analysis are summarized in Table 5. The distributions of payoffs from the timing rules across the individual gilts in each sub-sample are shown in Figure 13. In the earlier application of the timing rule, a form of out-of-sample testing was achieved by using a hold-out sample of bonds from within the overall cross section of bonds for a given time period. This hold-out sample was those bonds that did not display any significant autocorrelation. In the current context, the hold-out sample would be those bonds that did not show a reaction to the event day variable. However, since the timing rule is suggested by regression results that use the entire sub-sample period, even the hold-out bonds are not out-of-sample on a time series basis. To provide for a time series out-of sample test, we re-test any rules that generate significant profits (after transactions costs) within sample, on a separate later sub-sample for which the rule had not been pre-tested or underpinned by the results of the earlier regressions.[14]

14. When this procedure was applied to test the profits from the rules based upon observed autocorrelation, Section 4.2 above, no evidence of inefficiency could be detected within sample and so no (time series) out-of-sample testing was conducted.

In the period prior to QE1, Panel A of Table 5, an active timing rule that had bought gilts a day ahead of an issuance day (of that gilt or any other gilt) and sold them at the end of the issuance would have generated a return 25 percentage points higher than a buy-and-hold position across the sub-sample. This difference is significant ($p<0.001$). This is so whether or not the bonds in the sub-sample actually had a significantly positive coefficient on the issuance indicator variable in the regressions in Table 4, Panel A. However, for the cross-section hold-out sample bonds, the returns were only marginally better than a risk-free deposit ($p=0.088$). An active timing rule that bought gilts ahead of MPC meeting days and sold them at the end of the day of the MPC meeting would have generated a return 20 percentage points higher than a buy-and-hold position across the same sub-sample. This difference is also significant ($p<0.001$). Again, this is so whether the bonds are in-sample (exhibit a significant regression coefficient) or out-of-sample. The difference in the performance of the timing rule between the two subsets of bonds is not significant. The bid-ask spreads in the market at this time had a median value of around 13 basis points and an inter-quartile range of between 8 and 18 basis points. The break-even transaction costs for the timing rules applied to the bonds in this sub-sample are mostly within this range, with no particular set of bonds systematically able to exceed the costs of the bid-ask spread.

We undertake a time series out-of-sample test by applying the same rule within the post QE1 period, selected as there are the fewest confounding events in that sub-sample. These results are in Panel B of Table 5, directly below the corresponding in-sample results. For both the rule applied to MPC days and to days of general issuance, the active timing rule produced returns significantly worse than a buy and hold strategy ($p<0.01$), and so there is no evidence of any inefficiency relating to the absorption of information released on MPC days or revealed through issuance activity. The removal of these inefficiencies, which were present prior to QE1, suggests that the heightened market activity of QE, and associated reduction in bid-ask spreads, has indeed improved the functioning of the gilt market.

During the QE1 period, undertaking a timing rule that involved buying ahead of the day of a purchase auction and selling after the auction has taken place would have generated a return some 10 percentage points greater than a buy-and-hold strategy, see Panel A of Table 5. The positive return to holding gilts over the APF days is consistent with the significant fall in yields observed on these days by Joyce and Tong (2012). While these yield effects suggest that QE is able to influence the gilt market in a manner consistent with the portfolio balance transmission channel, our analysis also enables the side effects for gilt market investors to be determined. The spreads in the market during this period were considerably lower than during the pre-QE1 period, as shown in Figure 12, with a median value around 6 basis points and an inter-quartile range of between 4 and 10 basis points. The break-even transactions costs for the timing rule are towards the upper end of this range suggesting that there were more likely some profitable opportunities around for investors around the days of purchase auctions. This suggests that gilt prices were overreacting to the general purchase activity associated with QE. By contrast, the timing rule applied specifically to the event days indicating the purchase of a substitute gilt, did not provide returns in excess of a passive strategy or risk-free alternative.

The QE2&3 phase provides an out-of-sample period (relative to the QE1 phase being an in-sample period) within which to test the timing rule applied to APF event days. These results, in Panel B of Table 5, show a continuation of the opportunity for excess returns to an active trading strategy seen in-sample during QE1, in Panel A. No out-of-sample test was necessary in the case of purchases of substitute bonds, where no profits were found in-sample.

If we now treat the QE2&3 phase as an in-sample period, we have no possibility of testing the rules out-of-sample within our overall sample period. Instead, we split this sub-sample into two further sub-periods, which separates out the QE2 and QE3 phases. We use the QE2 period as the in-sample period, and the QE3 period as an out-of-sample period. To establish whether there are any potentially profitably opportunities we run further event-based regressions, equation (10), for the QE2 period. These are reported in Table 4, Panel E. We then test appropriate timing rules on both the QE2 period (in-sample) and the QE3 period (out-of-sample).[15]

The regressions for the QE2 period suggest that there may be profitable opportunities arising from trading in response to APF days, own purchases and own issuance. The annualized excess returns implicit in the regression coefficients in each case are 73 percent, 275 percent and 65 percent. In-sample, the timing rule applied to the APF event days generates a cumulative trading position of 6 percent greater than the passive strategy. The breakeven transaction costs averaged 9 percent, while during this time bid-ask spreads

15. We also report the regression results for the QE3 period (Panel F, Table 4), for the sake of completion, but do not use these to direct timing rules.

averaged around 7 percent. As was seen during the QE1 phase, returns could have been generated in excess of the costs of trading. Because only one bond displayed a significant regression coefficient in response to APF event days during the QE2 sample, all but this bond form the cross section hold-out sample, which largely mirrors the full sample results. The single in-sample bond does not appear to be an outlier (p=0.13). The fact that only one bond in the QE2 period gives any signal of a possible continuation of profits from an active timing strategy based upon APF days in QE1, helps mitigate against the potential for the QE2&3 period not being regarded as a robust out-of- sample period (relative to QE1 as an in-sample period), when the data has already been examined. For the QE2 period specifically, we can use the QE3 period as an out-of-sample test period. During QE3, the active timing rule produces returns only 2 percentage points above a passive buy and hold strategy, but this difference is statistically significant (p<0.01). However, transactions costs are almost at the same level as the breakeven costs that can be incurred by the active trading strategy. This suggests that by the end of the QE3 phase, any anomalous pricing associated with APF activity had been removed by market activity.

When the timing rule is applied to own purchase events, it does not produce excess returns even on an in-sample basis. By contrast, when the rule is applied to own issuance events, it generates a statistically significant difference in the payoffs between the active strategy and a passive alternative (p=0.002). However, the difference in payoff is less than 1 percent on an annualized basis. When the rule is tested out-of-sample, the QE3 period, it underperforms both a passive strategy and also a risk-free alternative. This indicates that by the time of the third phase of QE, the gilt market was reacting efficiently to the information revealed by bond market events.

## 7. The determinants of the decrease in bid-ask spreads

Considering the trading rule results collectively, the evidence regarding the excess returns to investing in gilts across purchase auction days during QE1 and QE2 suggests that QE activity did temporarily disrupt the price efficiency of the gilt market. Had not also the spreads in the market reduced, the potential excess returns available to investors would have been even greater. This raises the question of whether the same factors that might have been disrupting the gilt market were at work also in driving the spreads lower during the phases of QE. To examine this possibility, we repeat the regression analysis, equation (10), using the spread as the dependent variable. As this regression model contains both variables relating directly to QE, as well as other variable likely to affect spreads, such as issuance activity, we can disentangle the causes of the drop in spreads.

The results from these regressions, applied to each bond, and examined separately for each sub-sample period, are shown in Table 6. In the pre-QE1 period, there is evidence that spreads would fall on days that the MPC announced the results of their monthly meeting. This result is repeated also in the period between the end of QE1 and the beginning of QE2. This reduction is consistent with information-based explanations of the bid-ask spread, and implies that MPC announcements are associated with a reduction in uncertainty. During the phases of QE, there is little evidence to suggest that spreads are dropping specifically in response to asset purchase activity. This provides some further robustness to the companion regressions using returns, in Table 4, as this means that those results were not confounded by temporary reductions in spreads that might appear to exaggerate returns. There is also little evidence that issuance activity was having any systematic influence over the spreads on gilts during any of the sub-sample periods. The variable that does seem to be driving the reduction in spreads, however, is the share of ownership of the gilts with the Bank of England. This is particularly the case for medium and long term gilts. The coefficient on this term is negative suggesting that as Bank of England ownership increased, so spreads were driven down. The strength of the variable increases through the phases of QE pointing to this generating a sustained decrease in spreads in the market in comparison to the pre-QE1 phase. There are potentially several competing mechanisms at work in the relationship between Bank of England ownership share and spreads. As the ownership share is the accumulated result of the APF purchases, the boost to liquidity from the Bank's participation in the market would indicate that spreads would decline. But, the Bank's purchases are also reducing the stock of actively traded gilts, and this could put upward pressure on spreads. It is also possible that the positive signaling aspects of the Bank's activity, in that regular and continuing QE purchases are signaling its commitment to the unconventional monetary stimulus, could also act to improve the spreads in the gilts market, reflecting the increased stability of markets and the wider economy. The empirical evidence points to the improved liquidity and reduced uncertainty associated with the Bank's purchases as having generated a permanent fall in spreads.

## 8. Conclusion

This study has examined the behavior of UK bond returns during the recent experience of quantitative easing, using samples before, during and between phases of QE to provide comparative evidence. By contrast to prior studies that have use mainly event study methods, or dataset concerned only with QE related activity, this study uses a broader range of time series and regression methods, and controls for wider market activity during the phases of QE. Moreover, the focus of this study is not on establishing whether QE, operated through the bond market, was working, but is on discovering whether QE activity generated beneficial or detrimental side effects for the bond market. Since the bond market is the main instrument with which the UK government finances its spending deficit, such side effects could have material consequences for the cost of funding government expenditure. Thus, this study offers the first evidence as to whether QE could have beneficial or detrimental economic side effects.

The main findings are as follows. QE resulted in a substantial and statistically significant drop in the costs of trading gilts, with the median bid-ask spread dropping to one-half its level prior to QE1. This level has been sustained since this time, and did not increase in the period between QE1 and QE2. This in itself reduces the costs to investing for participants in the gilt market and should feed through to improved costs of new issuance for the government. We find that the spread displays temporary drops on the days that the MPC announces the results of its monthly meetings, while the permanent decrease throughout and beyond the phases of QE is shown to be driven by the Bank of England's increasing ownership share, which reflects its contributions to the liquidity of the market and the reduction of uncertainty.

The first phase of QE was associated with the disappearance of some significant first order return autocorrelation that, although it could not be exploited to earn excess returns, nonetheless represents an improvement in pricing efficiency as a result of QE1. However, in the period between QE1 and QE2, and during QE2 and QE3, autocorrelation in returns appeared again, but at higher orders. Changes in autocorrelation, which we argue reflect the speed of information processing in the market, are consistent with the improved functioning of the market arising during the phases of QE and, in particular, the reduction in spreads. These reductions enable smaller pricing anomalies to be traded away.

Our regression analysis allowed us to consider the impact of gilt purchase auctions controlling for other market events, such as issuance and QE announcements, the former of which was very frequent during the sample period. Consistent with earlier event studies, we find significant increases in price (implying reductions in yields) associated with days of asset purchases. However, by contrast to the event studies, we find that it matters more that the day is a purchase auction day than that a particular bond is being purchased. When indicator variables separated both own purchases from other bonds being purchased, the own purchases had little incremental impact. Similarly, we found little evidence that the purchases of near substitute bonds were influencing prices. This suggests that portfolio balance effects may operate between the gilt market and other assets, but are less likely to work within the gilt market. The impact of asset purchase days was also broadly similar in each of the QE periods, which is more in line with the results of Banerjee et al (2012) than those of Joyce et al (2012). By contrast to our results for the autocorrelation analysis, the effects of gilt purchases on gilt returns could have been exploited by investors to have earned excess returns. However, when testing these rules on an out-of-sample basis, we find that by the time of QE3, profitable opportunities that may have arisen temporarily during QE1 and QE2, could no longer produce excess returns sufficient to exceed transactions costs measured by the bid-ask spread. This indicates that while the gilt market did experience some temporary disruption to efficient pricing during the early phases of QE, even on an out-of-sample basis, these had largely disappeared by the end of QE3.

As there were many occasions during the QE periods when bonds were being issued on the same days as they were being purchased by the Bank of England, the exploitable excess returns to investors on these days could have changed the costs of bond issuance. These excess returns indicate an upward pressure on prices on all days of gilt purchases, which could put an upward pressure on the price of gilts being issued by the Treasury's Debt Management Office. If this was happening, then gilts may have been sold at unfairly low yields. While this is good news from the viewpoint of the costs of debt issuance, and for short-term investors in gilts, it could have negative consequences in terms of reducing the attractiveness of longer-term investment in gilts. That the excess returns seem to have disappeared by the end of QE3 suggests that no long term effects on the attractiveness of gilt investment may have been incurred. Indeed, the fact that there seems to have been a permanent reduction in gilt spreads during this time suggests that the pressure on debt issuance costs is most likely to be downwards.

Overall, our conclusion is that there have been some side effects of quantitative easing for the UK bond market and that these are mainly beneficial. However, the return regularities associated with purchase auction days indicates that further research to quantify the impact on the cost of debt management is desirable. That is a topic for future research.

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Table 1: Distribution of UK Government Bonds to the sub-samples

This table contains the list of gilts whose return series are analysed in this paper. A value of 1 indicates inclusion in the sub-sample.

| | | Pre-QE | QE1 | Post-QE1 | QE2 and QE3 |
|---|---|---|---|---|---|
| | Bond Name | 02/01/04-10/03/09 | 11/03/09-26/01/10 | 27/01/10-07/10/11 | 08/10/11-10/05/13 |
| 1 | TREASURY 4.5% 2007 | 1 | | | |
| 2 | TREASURY 8.5% 2007 | 1 | | | |
| 3 | TREASURY 7.25% 2007 | 1 | | | |
| 4 | TREASURY 5% 2008 | 1 | | | |
| 5 | TREASURY 4% 2009 | 1 | | | |
| 6 | TREASURY 5.75% 2009 | 1 | | | |
| 7 | TREASURY 4.75% 2010 | 1 | | | |
| 8 | TREASURY 6.25% 2010 | 1 | | | |
| 9 | TREASURY 4.25% 2011 | 1 | 1 | | |
| 10 | CONVERSION 9% 2011 | 1 | 1 | | |
| 11 | TREASURY 3.25% 2011 | | 1 | | |
| 12 | TREASURY 5% 2012 | 1 | 1 | | |
| 13 | TREASURY 5.25% 2012 | 1 | 1 | 1 | |
| 14 | TREASURY 4.5% 2013 | 1 | 1 | 1 | |
| 15 | TREASURY 8% 2013 | 1 | 1 | 1 | |
| 16 | TREASURY 2.25% 2014 | | 1 | 1 | 1 |
| 17 | TREASURY 5% 2014 | 1 | 1 | 1 | 1 |
| 18 | TREASURY 2.75% 2015 | | | 1 | 1 |
| 19 | TREASURY 4.34% 2015 | 1 | 1 | 1 | 1 |
| 20 | TREASURY 8% 2015 | 1 | 1 | 1 | 1 |
| 21 | TREASURY 2% 2016 | | | | 1 |
| 22 | TREASURY 4% 2016 | 1 | 1 | 1 | 1 |
| 23 | TREASURY 8.75% 2017 | 1 | 1 | 1 | 1 |
| 24 | TREASURY 5% 2018 | 1 | 1 | 1 | 1 |
| 25 | TREASURY 4.5% 2019 | | 1 | 1 | 1 |
| 26 | TREASURY 3.75% 2019 | | | 1 | 1 |
| 27 | TREASURY 4.75% 2020 | 1 | 1 | 1 | 1 |
| 28 | TREASURY 3.75% 2020 | | | | 1 |
| 29 | TREASURY 8% 2021 | 1 | 1 | 1 | 1 |
| 30 | TREASURY 3.75% 2021 | | | | 1 |
| 31 | TREASURY 4% 2022 | | 1 | 1 | 1 |
| 32 | TREASURY 5% 2025 | 1 | 1 | 1 | 1 |
| 33 | TREASURY 4.25% 2027 | 1 | 1 | 1 | 1 |
| 34 | TREASURY 6% 2028 | 1 | 1 | 1 | 1 |
| 35 | TREASURY 4.75% 2030 | | 1 | 1 | 1 |
| 36 | TREASURY 4.25% 3032 | 1 | 1 | 1 | 1 |
| 37 | TREASURY 4.5% 2034 | | | 1 | 1 |
| 38 | TREASURY 4.25% 2036 | 1 | 1 | 1 | 1 |
| 39 | TREASURY 4.75% 2038 | 1 | 1 | 1 | 1 |
| 40 | TREASURY 4.25% 2039 | | 1 | 1 | 1 |
| 41 | TREASURY 4.25% 2040 | | | | 1 |
| 42 | TREASURY 4.25% 2042 | 1 | 1 | 1 | 1 |
| 43 | TREASURY 4.25% 2046 | 1 | 1 | 1 | 1 |
| 44 | TREASURY 4.25% 2049 | | 1 | 1 | 1 |
| 45 | TREASURY 4.25% 2055 | 1 | 1 | 1 | 1 |
| 46 | TREASURY 4% 2060 | | | 1 | 1 |

## Table 2: Autocorrelation based Trading Rule Profits and Break Even Transactions Costs

"Passive" is the (average across all bonds in the sample of the) end of period value of a £1 investment at the start of the period from following a passive (buy-and-hold) strategy. "Active" is the average end of period value of a £1 investment at the start of the period following an active timing rule. "Rf" is the end of period value of a £1 investment in a short term money market deposit investment. Average (across all bonds) break-even transaction costs per one-way trade are reported alongside the sample period in parentheses. A value of, for example, 0.0003 means that the strategy will produce profits greater than buy-and-hold plus transactions costs, provided that transactions costs are less than 0.03% of the value of each one-way transaction. Bonds for which the autocorrelation underpinning the timing rule was not significant at a 5 percent level form an "out-of-sample" subset. t-test (paired) are p-values from tests whether the average end of period values are equal. The comparison is between the strategy with the result listed and the case with an empty cell. "No. Diff +" is the number of bonds for which the investment terminal value in that column exceeded the maximum of those in the other two columns. "t-test" (paired) in [out]" are p-values from tests of whether the averages from the in-sample bonds, "Average In", (those bonds for whom the autocorrelation was significant) and those for the out-of-sample bonds "Average Out" are the same across different trading strategies. "t-test In v Out" is the p-value of a test of whether the average profits from the active strategy are equal in the in-sample and out-of-sample cases.

| | Pre-QE1 – 02/01/04 – 10/03/09 (0.0003) | | | Post-QE1 – 27/01/10 – 07/10/11 (0.0002) | | | QE2&3 – 08/10/11 – 10/05/13 (0.0004) | | |
|---|---|---|---|---|---|---|---|---|---|
| Strategy | Rf | Passive | Active | Rf | Passive | Active | Rf | Passive | Active |
| Average | 1.2132 | 1.0542 | 1.2390 | 1.0110 | 1.1216 | 1.1751 | 1.0092 | 1.0341 | 1.1237 |
| t-test (paired) | | 0.000 | 0.127 | <0.001 | | <0.001 | 0.002 | | <0.001 |
| No. Diff + | | 3 | 16 | | 27 | 22 | | 23 | 24 |
| Average In | 1.2245 | 1.0309 | 1.2492 | 1.0110 | 1.1843 | 1.2937 | 1.0092 | 1.0510 | 1.1613 |
| Average Out | 1.1853 | 1.1112 | 1.2139 | 1.0110 | 1.0737 | 1.0844 | 1.0092 | 0.9761 | 0.9946 |
| t-test (paired) In | | 0.000 | 0.292 | <0.001 | | <0.001 | <0.001 | | <0.001 |
| t-test (paired) Out | | 0.070 | 0.048 | 0.003 | | 0.020 | 0.014 | | 0.007 |
| t-test (In v Out) | | | 0.364 | | | <0.001 | | | <0.001 |

**Table 3. Key QE Announcements relating to UK government bonds**

| Announcement date | Decision on QE | Other decisions |
|---|---|---|
| 19 January 2009 | The Chancellor of the Exchequer announces that the Bank of England will set up an asset purchase programme | |
| 30 January 2009 | Asset Purchase Facility Fund established. Exchange of letters between the Chancellor of the Exchequer and the Governor on 29 January 2009. | |
| 11 February 2009 | Bank of England's February *Inflation Report* and the associated press conference give strong indication that QE asset purchases are likely. | |
| 5 March 2009 | The MPC announces it will purchase £75 billion of assets over three months funded by central bank money. Conventional bonds likely to constitute the majority of purchases, restricted to bonds with residual maturity between 5 and 25 years. | Base rate reduced from 1% to 0.5%. |
| 11 March 2009 | First purchases of UK government bonds (gilts). | |
| 7 May 2009 | The MPC announces that the amount of QE asset purchases will be extended by a further £50 billion to £125 billion. | |
| 6 August 2009 | The MPC announces that QE asset purchases will be extended to £175 billion and that the buying range will be extended to gilts with a residual maturity greater than three years, and split between maturity ranges: 3-10 years, 10 to 25 years, and more than 25 years. | The Bank announces a gilt lending programme, which allows counterparties to borrow gilts from the APF's portfolio via the DMO in return for a fee and alternative gilts as collateral. |
| 5 November 2009 | The MPC announced that the amount of QE asset purchases would be extended to £200 billion. | |
| 4 February 2010 | The MPC announced that the amount of QE asset purchases would be maintained at £200 billion. | The MPC's press statement said that the committee would continue to monitor the appropriate scale of the asset purchase programme and that further purchases would be made should the outlook warrant them. |
| 6 October 2011 | The MPC announces that the amount of QE asset purchases will be extended by £75 billion to £275 billion. The start of QE2. | |
| 9 February 2012 | The MPC announces that the amount of QE asset purchases will be extended by a further £50 billion to £325 billion. | The maturity range boundaries are changed from 10 and 25 years to 7 and 15 years. |
| 5 July 2012 | The MPC announces that the amount of QE asset purchases will be extended by £50 billion to £375 billion. The start of QE3. | |

Source: Joyce at al (2011) and Joyce et al (2012).

## Table 4: Regression Tests of the Effects of Gilt-Market Events

This table contains the estimated coefficients from the following regression

$$r_t = b_0 + b_1 r_{t-1} + b_2 r_{t-2} + b_3 r_{t-3} + b_4 r_{t-4} + b_5 r_{t-5} + b_6 OI_t + b_7 IS_t + b_8 OP_t + b_9 PS_t + b_{10} PA_t + b_{11} SH_t + b_{12} QEA_t + b_{13} MPC_t + b_{14} BR_t$$

where $r_t$ is the daily bond return on day $t$, and the indicator variables take the value zero, unless the observations are on days that have (respectively) bond issuance, $IS_t$, bond purchases through the APF mechanism, $PA_t$ , own issuance, $OI_t$, own purchases, $OP_t$, purchases through the APF of close substitute bonds, $PS_t$, announcements relating to QE, $QEA_t$, meetings of the MPC, $MPC_t$, changes to the base rate, $BR_t$ , whereupon the indicator variables take the value one. The variable $SH_t$ is the percentage of the bond owned by the Bank of England (as a result of APF activity to that date) on day $t$. "No. Obs." is the number of observations, and $\overline{r_t}$ is the mean of the dependent variable. Estimated coefficients are statistically significant at the 1%, 5% and 10% levels when appended by ***,** and * respectively. The autoregressive coefficients are not reported to conserve space. Sub-samples exclude any variables that are zero for all bonds in the sub-sample

| | Panel A: Pre-QE1 - 02/01/04 – 10/03/09 | | | | | | Panel B: QE1 - 11/03/09 – 26/01/10 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | No. Obs. | $\overline{r_t}$ | $OI_t$ | $IS_t$ | $MPC_t$ | $BR_t$ | No. Obs. | $\overline{r_t}$ | $OI_t$ | $IS_t$ | $OP_t$ | $PS_t$ | $PA_t$ | $SH_t$ | $MPC_t$ | $QEA_t$ |
| TRSY 4.5% 2007 | 770 | 0.00000 | 0.00050 | 0.00008 | 0.00031*** | -0.00010 | | | | | | | | | | |
| TRSY 8.5% 2007 | 887 | -0.00014 | -0.00023 | 0.00004 | 0.00034*** | -0.00030 | | | | | | | | | | |
| TRSY 7.25% 2007 | 990 | -0.00009 | -0.00025 | 0.00008 | 0.00036*** | -0.00029 | | | | | | | | | | |
| TRSY 5% 2008 | 1052 | -0.00002 | -0.00040 | 0.00013 | 0.00033*** | -0.00033 | | | | | | | | | | |
| TRSY 4% 2009 | 1304 | 0.00002 | -0.00036* | 0.00017* | 0.00045*** | -0.00038 | | | | | | | | | | |
| TRSY 5.75% 2009 | 1306 | -0.00002 | 0.00004 | 0.00032*** | 0.00057*** | -0.00046 | | | | | | | | | | |
| TRSY 4.75% 2010 | 1082 | 0.00003 | 0.00019 | 0.00048*** | 0.00059** | -0.00073 | | | | | | | | | | |
| TRSY 6.25% 2010 | 1306 | 0.00000 | 0.00030 | 0.00051 | 0.00067*** | -0.00061 | | | | | | | | | | |
| TRSY 4.25% 2011 | 838 | 0.00007 | 0.00019 | 0.00074*** | 0.00048 | -0.00088 | 217 | -0.00006 | | 0.00007 | | | 0.00010 | | -0.00027 | 0.00036 |
| CVSN 9% 2011 | 1306 | -0.00006 | 0.00047 | 0.00058*** | 0.00071*** | -0.00063 | 217 | -0.00021 | | 0.00003 | | | 0.00019 | | -0.00030 | 0.00049 |
| TRSY 3.25% 2011 | | | | | | | 217 | 0.00001 | | 0.00011 | | | 0.00014 | | -0.00031 | 0.00016 |
| TRSY 5% 2012 | 1306 | 0.00005 | 0.00010 | 0.00074*** | 0.00079** | -0.00068 | 217 | -0.00004 | | 0.00011 | | | 0.00026 | | -0.00025 | 0.00005 |
| TRSY 5.25% 2012 | 495 | 0.00018 | 0.00057 | 0.00099*** | 0.00064 | -0.00049 | 217 | -0.00004 | -0.00182*** | 0.00020 | | | 0.00032 | | -0.00034 | 0.00029 |
| TRSY 4.5% 2013 | 251 | 0.00030 | -0.00045 | 0.00121* | 0.00063 | 5.18E-06 | 217 | -0.00004 | 0.00146** | 0.00017 | -0.00051 | -0.00038 | 0.00064** | 0.00076 | -0.00047 | -0.00022 |
| TRSY 8% 2013 | 1306 | -0.00001 | 0.00085 | 0.00083*** | 0.00090** | -0.00059 | 217 | -0.00012 | | 0.00011 | -0.00050 | -0.00039 | 0.00080** | 0.00013 | -0.00057 | 0.00248 |
| TRSY 2.25% 2014 | | | | | | | 209 | 0.00003 | -0.00005 | -0.00005 | -0.00017 | -0.00079 | 0.00104** | 0.00061 | -0.00065 | 0.00208 |
| TRSY 5% 2014 | 1306 | 0.00009 | 0.00098 | 0.00099*** | 0.00099** | -0.0002 | 217 | -0.00018 | -0.00018 | -0.00003 | 0.00157 | -0.00199** | 0.00125*** | 0.00145 | -0.00082 | 0.00112 |
| TRSY 4.34% 2015 | 1306 | 0.00010 | 0.00159 | 0.00097*** | 0.00108** | 1.55E-05 | 217 | -0.00021 | -0.01268*** | 0.00045 | -0.00302 | 0.00096 | 0.00143*** | 0.00082 | -0.00175 | 0.00175 |
| TRSY 8% 2015 | 1306 | 0.00003 | 0.00121 | 0.00098*** | 0.00103** | 0.000149 | 217 | -0.00029 | | 0.00005 | 0.00036 | -0.00189 | 0.00159*** | 0.00321 | -0.00134 | 0.00165 |
| TRSY 4% 2016 | 764 | 0.00014 | -0.00059 | 0.00154*** | 0.00044 | 0.000889 | 217 | -0.00024 | -0.00644*** | -0.00016 | -0.00178 | 0.00083 | 0.00133** | 0.00365 | -0.00145 | 0.00244 |
| TRSY 8.75% 2017 | 1306 | 0.00002 | 0.00095 | 0.00102*** | 0.00110** | 0.000152 | 217 | -0.00032 | | -0.00023 | -0.00163 | 0.00075 | 0.00146** | 0.00446 | -0.00139 | 0.00130 |
| TRSY 5% 2018 | 449 | 0.00039 | 0.00148 | 0.00135 | 0.00089 | 0.001894 | 217 | -0.00030 | | -0.00022 | -0.00266* | 0.00149 | 0.00135* | 0.00228 | -0.00177 | 0.00081 |
| TRSY 4.5% 2019 | | | | | | | 217 | -0.00032 | 0.00054 | -0.00018 | -0.00315** | 0.00161 | 0.00170** | 0.00598 | -0.00148 | -0.00101 |
| TRSY 4.75% 2020 | 999 | 0.00012 | 0.00156 | 0.00121** | 0.00112 | 0.00025 | 217 | -0.00030 | -0.00448*** | -0.00012 | 0.00255* | -0.00118 | 0.00134 | 0.00397 | -0.00203 | 0.00161 |
| TRSY 8% 2021 | 1306 | 0.00004 | 0.00124 | 0.00114** | 0.00102* | 0.000304 | 217 | -0.00036 | | -0.00026 | 0.00316* | 0.00125 | 0.00071 | 0.00511 | -0.00166 | 0.00186 |
| TRSY 4% 2022 | | | | | | | 217 | -0.00028 | 0.00359** | -0.00062 | 0.00048 | 0.00272* | 0.00049 | 0.00311 | -0.00205 | 0.00184 |
| TRSY 5% 2025 | 1306 | 0.00007 | -0.00069 | 0.00151** | 0.00115 | 0.001043 | 217 | -0.00037 | -0.00051 | -0.00058 | 0.01099** | -0.00706 | 0.00004 | 0.00524 | -0.00105 | 0.00508 |
| TRSY 4.25% 2027 | 630 | 0.00009 | -0.00257 | 0.00269** | 0.00078 | 0.003109 | 217 | -0.00037 | 0.00609*** | -0.00099 | -0.00279 | 0.00659*** | 0.00020 | 0.00470 | -0.00120 | 0.00660 |
| TRSY 6% 2028 | 1306 | 0.00006 | 0.00045 | 0.00145** | 0.00108 | 0.001303 | 217 | -0.00036 | 0.00151 | -0.00055 | 0.00336* | -0.00187 | 0.00059 | 0.00343 | -0.00120 | 0.00361 |
| TRSY 4.75% 2030 | | | | | | | 217 | -0.00037 | 0.01107 | -0.00093 | 0.00269 | -0.00289 | 0.00071 | 0.00779 | -0.00154 | 0.00418 |
| TRSY 4.25% 3032 | 1306 | 0.00008 | -0.00027 | 0.00157** | 0.00110 | 0.001555 | 217 | -0.00036 | 0.00262 | -0.00088 | 0.00405** | -0.00162 | 0.00049 | 0.00779 | -0.00182 | 0.00782 |
| TRSY 4.25% 2036 | 1306 | 0.00006 | -0.00102 | 0.00149* | 0.00101 | 0.001362 | 217 | -0.00024 | | -0.00106 | -0.00342 | -0.00598*** | 0.00076 | -0.00017 | -0.00122 | 0.00734 |
| TRSY 4.75% 2038 | 1237 | 0.00009 | -0.00173 | 0.00163* | 0.00084 | 0.00148 | 217 | -0.00023 | -0.01027*** | -0.00096 | -0.00332 | -0.00590*** | 0.00072 | -0.00074 | -0.00148 | 0.00756 |
| TRSY 4.25% 2039 | | | | | | | 217 | -0.00014 | -0.00031 | -0.00112 | -0.00245 | -0.00590*** | 0.00122 | -0.00083 | -0.00150 | 0.00776 |
| TRSY 4.25% 2042 | 442 | 0.00021 | -0.00017 | 0.00157 | 0.00227 | 0.002445 | 217 | -0.00011 | | -0.00132 | -0.00409* | -0.00672*** | 0.00133 | -0.00870 | -0.00165 | 0.00803 |
| TRSY 4.25% 2046 | 711 | -0.00004 | -0.00416 | 0.00184 | 0.00081 | 0.001628 | 217 | -0.00006 | | -0.00137 | -0.00369 | -0.00711*** | 0.00154 | -0.00466 | -0.00187 | 0.00907 |
| TRSY 4.25% 2049 | | | | | | | 217 | -0.00003 | 0.00608 | -0.00141 | -0.00401 | -0.00725*** | 0.00144 | -0.00431 | -0.00175 | 0.00977 |
| TRSY 4.25% 2055 | 953 | 0.00001 | 0.00144 | 0.00110 | 0.00076 | 0.00157 | 217 | -0.00007 | | -0.00157 | -0.00386 | -0.00767*** | 0.00194 | -0.00124 | -0.00212 | 0.01081 |

## Table 4: Regression Tests of the Effects of Gilt-Market Events (cont.)

| | Panel C: Post QE1 - 27/01/10 – 07/10/11 (No. Obs. = 424) | | | | | | Panel D: QE2&3 - 10/10/11 – 08/05/13 (No. Obs. = 395) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | $\bar{r}_t$ | $OI_t$ | $IS_t$ | $SH_t$ | $MPC_t$ | $QEA_t$ | $\bar{r}_t$ | $OI_t$ | $IS_t$ | $OP_t$ | $PS_t$ | $PA_t$ | $SH_t$ | $MPC_t$ | $QEA_t$ |
| TRSY 5.25% 2012 | -0.00011 | 0.00137*** | -0.00013 | | 0.00009 | 0.00005 | | | | | | | | | |
| TRSY 4.5% 2013 | -0.00004 | -0.00011 | -0.00016 | 0.00450 | -0.00012 | 0.00032 | | | | | | | | | |
| TRSY 8% 2013 | -0.00012 | | -0.00019 | | -0.00021 | 0.00047 | | | | | | | | | |
| TRSY 2.25% 2014 | 0.00011 | 0.00092*** | -0.00015 | -0.00039 | -0.00014 | 0.00102 | -0.00005 | 0.00000 | 0.00001 | | 0.00015 | 0.00001 | 0.03529** | 0.00003 | 0.00025 |
| TRSY 5% 2014 | 0.00004 | -0.00102*** | -0.00017 | 0.00302 | -0.00021 | 0.00119 | -0.00013 | 0.00039 | -0.00004 | | 0.00019 | 0.00000 | 0.00489* | 0.00005 | 0.00046 |
| TRSY 2.75% 2015 | 0.00015 | -0.00121*** | -0.00025 | 0.03463 | -0.00002 | 0.00029 | -0.00004 | -0.00050 | 0.00003 | 0.00099** | -0.00002 | 0.00000 | -0.00416 | 0.00001 | 0.00085 |
| TRSY 4.34% 2015 | 0.00011 | 0.00036 | -0.00022 | 0.00184 | -0.00019 | 0.00045 | -0.00008 | -0.00046 | 0.00001 | -0.00012 | 0.00085** | 0.00004 | -0.00252 | 0.00001 | 0.00137 |
| TRSY 8% 2015 | 0.00003 | | -0.00023 | | -0.00022 | 0.00046 | -0.00016 | -0.00044 | -0.00002 | 0.00051 | 0.00020 | 0.00005 | -0.00370 | 0.00002 | 0.00139 |
| TRSY 2% 2016 | | | | | | | 0.00003 | -0.00042 | 0.00001 | 0.00059* | -0.00035 | 0.00011 | -0.00140 | -0.00011 | 0.00224* |
| TRSY 4% 2016 | 0.00019 | -0.00047 | -0.00027 | 0.00697 | -0.00024 | 0.00036 | -0.00001 | -0.00091 | 0.00002 | 0.00096** | -0.00060 | 0.00021 | -0.00431 | -0.00011 | 0.00252 |
| TRSY 8.75% 2017 | 0.00010 | | -0.00032 | | -0.00033 | 0.00042 | -0.00009 | -0.00085 | -0.00011 | 0.00124** | -0.00087* | 0.00051 | -0.00190 | -0.00016 | 0.00276 |
| TRSY 5% 2018 | 0.00022 | 0.00322*** | -0.00042 | 0.00928 | -0.00030 | 0.00285*** | 0.00002 | -0.00028 | -0.00013 | 0.00086 | -0.00076 | 0.00067* | 0.01220 | -0.00020 | 0.00305 |
| TRSY 4.5% 2019 | 0.00027 | | -0.00040 | | -0.00016 | 0.00122 | 0.00007 | 0.00047 | -0.00029 | 0.00197*** | -0.00140** | 0.00079* | -0.00242 | -0.00023 | 0.00252 |
| TRSY 3.75% 2019 | 0.00031 | 0.00376*** | -0.00049 | -0.06458 | -0.00011 | 0.00096 | 0.00011 | -0.00162 | -0.00032 | 0.00031 | -0.00073 | 0.00093* | -0.00154 | -0.00029 | 0.00278 |
| TRSY 4.75% 2020 | 0.00027 | -0.00034 | -0.00045 | -0.00100 | -0.00033 | 0.00145 | 0.00009 | -0.00209 | -0.00042 | -0.00035 | -0.00045 | 0.00106* | -0.00631 | -0.00036 | 0.00190 |
| TRSY 3.75% 2020 | | | | | | | 0.00014 | -0.00247 | -0.00044 | -0.00001 | -0.00066 | 0.00105* | -0.00544 | -0.00040 | 0.00171 |
| TRSY 8% 2021 | 0.00020 | | -0.00044 | | -0.00013 | 0.00275 | 0.00004 | -0.00190 | -0.00040 | | -0.00082 | 0.00124** | 0.10066* | -0.00073 | 0.00127 |
| TRSY 3.75% 2021 | | | | | | | 0.00014 | -0.00182 | -0.00025 | 0.00001 | -0.00173** | 0.00177*** | -0.00148 | -0.00054 | 0.00132 |
| TRSY 4% 2022 | 0.00035 | -0.00124 | -0.00051 | 0.00006 | -0.00014 | 0.00065 | 0.00014 | 0.00026 | -0.00052 | -0.00155 | -0.00033 | 0.00131** | -0.00568 | -0.00072 | 0.00115 |
| TRSY 5% 2025 | 0.00037 | -0.00171 | -0.00054 | -0.02156 | -0.00041 | 0.00070 | 0.00013 | -0.00038 | -0.00032 | -0.00174 | -0.00044 | 0.00172** | -0.00077 | -0.00107 | 0.00086 |
| TRSY 4.25% 2027 | 0.00040 | 0.00267 | -0.00076 | -0.00980 | -0.00038 | 0.00061 | 0.00015 | 0.00076 | -0.00059 | -0.00088 | -0.00149 | 0.00188** | -0.00473 | -0.00126 | -0.00202 |
| TRSY 6% 2028 | 0.00035 | 0.00421*** | -0.00082 | -0.06026 | 0.00007 | 0.00051 | 0.00012 | -0.00247 | -0.00044 | -0.00268 | 0.00311* | 0.00055 | -0.00349 | -0.00119 | -0.00210 |
| TRSY 4.75% 2030 | 0.00039 | -0.00705*** | -0.00063 | -0.00738 | -0.00065 | 0.00104 | 0.00014 | -0.00016 | -0.00049 | -0.00510** | 0.00517** | 0.00077 | -0.00254 | -0.00131 | -0.00415 |
| TRSY 4.25% 3032 | 0.00039 | -0.00031 | -0.00085 | -0.03093 | -0.00043 | 0.00032 | 0.00016 | 0.00134 | -0.00063 | -0.00515** | 0.00493** | 0.00071 | -0.00457 | -0.00143 | -0.00528 |
| TRSY 4.5% 2034 | 0.00040 | 0.00395 | -0.00121 | -0.00650 | 0.00059 | 0.00151 | 0.00015 | -0.00206 | -0.00044 | -0.00346 | 0.00408* | 0.00071 | -0.00494 | -0.00162 | -0.00588 |
| TRSY 4.25% 2036 | 0.00040 | -0.00564*** | -0.00089 | -0.09976* | 0.00054 | 0.00174 | 0.00015 | -0.00263 | -0.00041 | -0.00607** | 0.00639** | 0.00087 | 0.00064 | -0.00179 | -0.00689 |
| TRSY 4.75% 2038 | 0.00039 | -0.00586*** | -0.00102 | 0.02265 | 0.00057 | 0.00273 | 0.00014 | -0.00346* | -0.00054 | 0.00284 | -0.00021 | 0.00080 | -0.01159 | -0.00197 | -0.00763 |
| TRSY 4.25% 2039 | 0.00040 | -0.00103 | -0.00117 | -0.03182* | 0.00085 | 0.00405 | 0.00014 | -0.00399 | -0.00062 | 0.00040 | 0.00163 | 0.00087 | -0.00345 | -0.00208 | -0.00812 |
| TRSY 4.25% 2040 | | | | | | | 0.00014 | -0.00846* | -0.00030 | 0.00016 | 0.00207 | 0.00091 | -0.00206 | -0.00227 | -0.00855 |
| TRSY 4.5% 2042 | 0.00040 | | -0.00132 | | 0.00056 | 0.00526 | 0.00013 | -0.00725** | -0.00008 | 0.00542** | -0.00180 | 0.00081 | -0.00558 | -0.00154 | -0.00988 |
| TRSY 4.25% 2046 | 0.00041 | 0.00483*** | -0.00149 | -0.01563 | 0.00074 | 0.00684 | 0.00012 | -0.00393 | -0.00071 | 0.00358 | -0.00058 | 0.00084 | -0.01086 | -0.00259 | -0.00991 |
| TRSY 4.25% 2049 | 0.00041 | -0.00872*** | -0.00134 | -0.06738 | 0.00077 | 0.00785 | 0.00012 | -0.00354 | -0.00067 | 0.00745*** | -0.00316 | 0.00084 | -0.01002 | -0.00284 | -0.01082 |
| TRSY 4.25% 2055 | 0.00042 | 0.00452*** | -0.00158 | -0.05053 | 0.00089 | 0.00842 | 0.00013 | -0.00398 | -0.00081 | 0.00684** | -0.00287 | 0.00082 | -0.01972 | -0.00315 | -0.01267 |
| TRSY 4% 2060 | 0.00043 | 0.00065 | -0.00170 | -0.06208*** | 0.00025* | 0.01218 | 0.00015 | 0.00052 | -0.00095 | 0.00774** | -0.00348 | 0.00102 | -0.00755 | -0.00332 | -0.01402 |

# Table 4: Regression Tests of the Effects of Gilt-Market Events (cont.)

| | Panel E: QE2 - 10/10/11 – 31/05/12 (No. Obs. = 160) | | | | | | | | | Panel F: QE3 - 01/06/12 – 08/05/13 (No. Obs. 230) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | $\bar{r}_t$ | $OI_t$ | $IS_t$ | $OP_t$ | $PS_t$ | $PA_t$ | $SH_t$ | $MPC_t$ | $QEA_t$ | $\bar{r}_t$ | $OI_t$ | $IS_t$ | $OP_t$ | $PS_t$ | $PA_t$ | $SH_t$ | $MPC_t$ | $QEA_t$ |
| TRSY 2.25% 2014 | 0.00000 | -0.00020 | -0.00004 | 0.00000 | -0.00016 | 0.00002 | 0.12187*** | 0.00005 | -0.00033* | -0.00008 | 0.00036*** | -0.00001 | 0.00000 | -0.00009 | 0.00001 | 0.00998 | 0.00002 | 0.00097*** |
| TRSY 5% 2014 | -0.00006 | 0.00046 | -0.00011 | 0.00000 | 0.00023 | 0.00002 | 0.00086 | 0.00013 | -0.00058*** | -0.00017 | 0.00050*** | -0.00007 | 0.00000 | 0.00005 | 0.00000 | 0.00502 | 0.00001 | 0.00159*** |
| TRSY 2.75% 2015 | 0.00004 | -0.00112** | -0.00006 | 0.00123** | -0.00017 | 0.00004 | -0.00430 | 0.00022 | -0.00094** | -0.00008 | 0.00047*** | 0.00000 | 0.00000 | 0.00021 | 0.00003 | 0.04036 | -0.00002 | 0.00255*** |
| TRSY 4.34% 2015 | 0.00002 | -0.00131*** | -0.00012 | -0.00101** | -0.00174*** | 0.00000 | -0.00166 | 0.00034 | -0.00070 | -0.00014 | 0.00023 | -0.00004 | 0.00031 | 0.00000 | 0.00002 | -0.00128 | -0.00004 | 0.00324*** |
| TRSY 8% 2015 | -0.00005 | -0.00129*** | -0.00012 | 0.00056 | 0.00011 | 0.00003 | -0.00002 | 0.00033 | -0.00059 | -0.00023 | 0.00087*** | -0.00010 | 0.00000 | 0.00027 | 0.00001 | 0.02888 | 0.00001 | 0.00300*** |
| TRSY 2% 2016 | 0.00015 | -0.00125** | -0.00013 | 0.00120* | -0.00085 | 0.00014 | -0.00142 | 0.00032 | 0.00023 | -0.00003 | 0.00082** | -0.00004 | 0.00019 | -0.00008 | 0.00002 | -0.00158 | -0.00016 | 0.00397*** |
| TRSY 4% 2016 | 0.00012 | -0.00143*** | -0.00012 | 0.00181** | -0.00121* | 0.00023 | -0.00281 | 0.00037 | 0.00011 | -0.00009 | 0.00094** | -0.00003 | 0.00035 | -0.00016 | 0.00008 | -0.00135 | -0.00017 | 0.00463*** |
| TRSY 8.75% 2017 | 0.00008 | -0.00193* | -0.00035 | 0.00184** | -0.00149* | 0.00068 | -0.00077 | 0.00068 | -0.00049 | -0.00019 | 0.00099* | -0.00012 | 0.00086* | -0.00040 | 0.00016 | -0.00276 | -0.00032 | 0.00525*** |
| TRSY 5% 2018 | 0.00021 | -0.00208* | -0.00045 | 0.00100 | -0.00106 | 0.00083 | 0.02083 | 0.00077 | -0.00039 | -0.00009 | 0.00147** | -0.00012 | 0.00074 | -0.00032 | 0.00016 | 0.00634 | -0.00038 | 0.00566*** |
| TRSY 4.5% 2019 | 0.00033 | 0.00154 | -0.00089 | 0.00346*** | -0.00273** | 0.00098 | 0.00133 | 0.00126 | -0.00206 | -0.00007 | 0.00076 | -0.00004 | 0.00111 | -0.00059 | 0.00058 | -0.01178* | -0.00039 | 0.00475*** |
| TRSY 3.75% 2019 | 0.00039 | -0.00237 | -0.00098 | 0.00105 | -0.00152 | 0.00119 | 0.00061 | 0.00125 | -0.00275 | -0.00004 | 0.00063 | -0.00007 | 0.00001 | -0.00018 | 0.00043 | -0.00066 | -0.00061 | 0.00664*** |
| TRSY 4.75% 2020 | 0.00039 | -0.00298 | -0.00113 | 0.00011 | -0.00094 | 0.00137 | 0.01285 | 0.00126 | -0.00425* | -0.00007 | 0.00048 | -0.00009 | -0.00043 | -0.00006 | 0.00054 | 0.00005 | -0.00066 | 0.00631*** |
| TRSY 3.75% 2020 | 0.00045 | -0.00353 | -0.00121 | 0.00105 | -0.00159 | 0.00134 | 0.00059 | 0.00135 | -0.00538** | -0.00004 | 0.00011 | -0.00002 | -0.00082 | -0.00006 | 0.00064 | -0.00318 | -0.00075 | 0.00682*** |
| TRSY 8% 2021 | 0.00035 | -0.00331* | -0.00091 | 0.00000 | -0.00024 | 0.00097 | 0.45734*** | 0.00048 | -0.00540*** | -0.00014 | 0.00096 | -0.00008 | 0.00000 | -0.00128 | 0.00122** | 0.09021 | -0.00081 | 0.00642*** |
| TRSY 3.75% 2021 | 0.00047 | -0.00337* | -0.00059 | -0.00006 | -0.00204* | 0.00220** | 0.00605 | 0.00169 | -0.00744*** | -0.00005 | 0.00081 | 0.00000 | -0.00016 | -0.00137 | 0.00132* | 0.00059 | -0.00106 | 0.00782*** |
| TRSY 4% 2022 | 0.00047 | -0.00020 | -0.00124 | -0.00257 | 0.00044 | 0.00141 | -0.02393* | 0.00126 | -0.00667** | -0.00005 | 0.00241 | -0.00018 | -0.00012 | -0.00144 | 0.00129* | -0.00155 | -0.00114 | 0.00806*** |
| TRSY 5% 2025 | 0.00051 | -0.00063 | -0.00111 | -0.00251 | 0.00025 | 0.00178 | 0.00808 | 0.00110 | -0.00941*** | -0.00009 | 0.00271 | -0.00005 | -0.00037 | -0.00163 | 0.00156* | 0.00121 | -0.00155 | 0.00896*** |
| TRSY 4.25% 2027 | 0.00056 | 0.00228 | -0.00203 | -0.00055 | -0.00131 | 0.00196 | -0.00020 | 0.00131 | -0.01577*** | -0.00009 | 0.00091 | 0.00028 | -0.00134 | -0.00194 | 0.00179* | 0.01523 | -0.00172 | 0.00890*** |
| TRSY 6% 2028 | 0.00051 | -0.00338 | -0.00166 | -0.00368* | 0.00415** | 0.00041 | 0.00845 | 0.00119 | -0.01557*** | -0.00011 | 0.00032 | 0.00021 | 0.00116 | -0.00047 | 0.00061 | 0.07028 | -0.00167 | 0.00863*** |
| TRSY 4.75% 2030 | 0.00057 | -0.00264 | -0.00176 | -0.00469* | 0.00521** | 0.00057 | 0.01440 | 0.00132 | -0.01957*** | -0.00009 | -0.00005 | 0.00017 | 0.00007 | 0.00000 | 0.00050 | -0.01164 | -0.00175 | 0.00753** |
| TRSY 4.25% 3032 | 0.00059 | 0.00568 | -0.00276 | -0.00586** | 0.00548** | 0.00036 | 0.00246 | 0.00180 | -0.02225*** | -0.00006 | -0.00382 | 0.00062 | -0.00004 | 0.00021 | 0.00074 | -0.00578 | -0.00189 | 0.00724** |
| TRSY 4.5% 2034 | 0.00059 | -0.00361 | -0.00198 | -0.00477* | 0.00535** | 0.00049 | -0.00493 | 0.00152 | -0.02314*** | -0.00007 | 0.00118 | 0.00034 | 0.00920*** | -0.00808*** | 0.00071 | 0.00516 | -0.00219 | 0.00816** |
| TRSY 4.25% 2036 | 0.00060 | -0.00335 | -0.00221 | -0.00561* | 0.00646** | 0.00064 | 0.00334 | 0.00184 | -0.02425*** | -0.00005 | -0.00048 | 0.00054 | -0.00350 | 0.00342 | 0.00089 | 0.08984 | -0.00232 | 0.00657** |
| TRSY 4.75% 2038 | 0.00061 | -0.00168 | -0.00223 | 0.00605** | -0.00135 | 0.00063 | -0.01041 | 0.00176 | -0.02469*** | -0.00006 | 0.00025 | 0.00045 | -0.00660 | 0.00583 | 0.00080 | 0.06733 | -0.00252 | 0.00574* |
| TRSY 4.25% 2039 | 0.00062 | -0.00354 | -0.00258 | 0.00273 | 0.00121 | 0.00061 | -0.00098 | 0.00205 | -0.02584*** | -0.00005 | 0.00095 | 0.00052 | -0.00603* | 0.00500* | 0.00112 | 0.10457 | -0.00262 | 0.00538 |
| TRSY 4.25% 2040 | 0.00064 | -0.01137 | -0.00173 | 0.00204 | 0.00188 | 0.00073 | -0.00125 | 0.00168 | -0.02650*** | -0.00005 | 0.00000 | 0.00039 | -0.00548 | 0.00489 | 0.00059 | 0.00252 | -0.00289 | 0.00497 |
| TRSY 4.25% 2042 | 0.00062 | -0.00768 | -0.00161 | 0.00778** | -0.00180 | 0.00071 | -0.00025 | 0.00297 | -0.02843*** | -0.00005 | -0.00680 | 0.00091 | 0.00021 | 0.00037 | 0.00063 | 0.00904 | -0.00226 | 0.00384 |
| TRSY 4.25% 2046 | 0.00064 | -0.00261 | -0.00306 | 0.00612* | -0.00081 | 0.00059 | -0.01201 | 0.00239 | -0.02919*** | -0.00006 | -0.00078 | 0.00052 | -0.00481 | 0.00442 | 0.00048 | -0.01768 | -0.00335 | 0.00352 |
| TRSY 4.25% 2049 | 0.00065 | -0.00241 | -0.00314 | 0.00725* | -0.00174 | 0.00057 | -0.02289 | 0.00245 | -0.03057 | -0.00005 | -0.00338 | 0.00060 | 0.00940*** | -0.00716*** | 0.00062 | 0.00106 | -0.00363 | 0.00338 |
| TRSY 4.25% 2055 | 0.00071 | -0.00315 | -0.00331 | 0.00779* | -0.00181 | 0.00058 | -0.02815 | 0.00219 | -0.03174 | -0.00005 | -0.00194 | 0.00067 | 0.00574 | -0.00496 | 0.00078 | 0.01395 | -0.00396 | 0.00095 |
| TRSY 4% 2060 | 0.00079 | -0.00248 | -0.00347 | 0.00788* | -0.00157 | 0.00079 | -0.00548 | 0.00242 | -0.03364 | -0.00005 | 0.00400 | 0.00046 | 0.00645 | -0.00569 | 0.00099 | 0.02327 | -0.00429 | 0.00033 |

## Table 5: Event based Trading Rule Tests

"Passive" is the (average across all bonds in the sample of the) end of period value of a £1 investment at the start of the period from following a passive (buy-and-hold) strategy. "Active" is the average end of period value of a £1 investment at the start of the period following an active timing rule. "Rf" is the end of period value of a £1 investment in a short term money market deposit investment. Average (across all bonds) break-even transaction costs per one-way trade are reported alongside the sample period in parentheses. A value of, for example, 0.0003 means that the strategy will produce profits greater than buy-and-hold plus transactions costs, provided that transactions costs are less than 0.03% of the value of each one-way transaction. Bonds for which the event underpinning the timing rule was not significant at a 5 percent level form an "out-of-sample" subset. t-test (paired) are p-values from tests whether the average end of period values are equal. The comparison is between the strategy with the result listed and the case with an empty cell. "No. Diff +" is the number of bonds for which the investment terminal value in that column exceeded the maximum of those in the other two columns. "t-test" (paired) in [out]" are p-values from tests of whether the averages from the in-sample bonds, "Average In", (those bonds for whom the autocorrelation was significant) and those for the out-of-sample bonds "Average Out" are the same across different trading strategies. "t-test In v Out" is the p-value of a test of whether the average profits from the active strategy are equal in the in-sample and out-of-sample cases. Panels A and C contain the (time series) in-sample results for each trading rule suggested by the regression results in Table 6. Panels B and D contains the corresponding (time series) out-of-sample results for the same trading rules applied to a later sub-sample. If there are no matching out-of-sample results, then the (time series in-sample) active strategy did not beat the next best alternative either before or after transactions costs.

| | Rf | Passive | Active | Rf | Passive | Active | Rf | Passive | Active | Rf | Passive | Active |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Panel A | Issuance days (0.0011) | | | MPC days (0.0016) | | | APF days (0.0008) | | | Substitute Purchases (0.0000) | | |
| (In sample) | Pre-QE1 - 02/01/2004 – 10/03/2009 | | | | | | QE1 - 11/03/2009 – 26/01/10 | | | | | |
| Average | 1.2123 | 1.0537 | 1.3056 | 1.2123 | 1.0537 | 1.2591 | 1.0051 | 0.9582 | 1.0543 | 1.0051 | 0.9529 | 0.8794 |
| t-test(paired) | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| No. Diff + | | 1 | 25 | | 2 | 27 | | 0 | 28 | | 0 | 0 |
| Average In | 1.2204 | 1.0483 | 1.3110 | 1.2504 | 1.0231 | 1.2919 | 1.0051 | 0.9573 | 1.0383 | 1.0051 | 0.9653 | 0.8351 |
| Average Out | 1.1891 | 1.0693 | 1.2904 | 1.1716 | 1.0864 | 1.2242 | 1.0051 | 0.9586 | 1.0624 | 1.0051 | 0.9447 | 0.9090 |
| t-test (paired) In | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| t-test (paired) Out | | 0.041 | 0.015 | | 0.008 | 0.006 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| t-test (In v Out) | | | 0.726 | | | 0.040 | | | 0.017 | | | 0.007 |
| Panel B | Post-QE1 - 27/01/10 – 08/10/11 | | | | | | QE2&3 - 09/10/11 – 08/05/13 | | | | | |
| (Out of sample) | Issuance days (0.0000) | | | MPC days (0.0000) | | | APF days (0.0010) | | | | | |
| Average | 1.0109 | 1.1210 | 0.9948 | 1.0109 | 1.1210 | 1.0214 | 1.0091 | 1.0363 | 1.1452 | | | |
| t-test(paired) | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.001 | | 0.000 | | | |
| No. Diff + | | 27 | 0 | | 27 | 2 | | 0 | 26 | | | |
| Average In | | | | | | | 1.0091 | 1.0442 | 1.1058 | | | |
| Average Out | 1.0109 | 1.1210 | 0.9948 | 1.0109 | 1.1210 | 1.0214 | 1.0091 | 1.0325 | 1.1639 | | | |
| t-test (paired) In | | | | | | | 0.000 | | 0.000 | | | |
| t-test (paired) Out | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.038 | | 0.049 | | | |
| t-test (In v Out) | | | | | | | | | 0.066 | | | |
| Panel C | QE2 – 09/10/11 – 31/05/12 | | | | | | | | | | | |
| (In sample) | APF days (0.0009) | | | Own purchases (0.0000) | | | Own issuance (0.0007) | | | | | |
| Average | 1.0041 | 1.0641 | 1.1201 | 1.0041 | 1.0692 | 1.0680 | 1.0041 | 1.0641 | 1.0671 | | | |
| t-test(paired) | 0.000 | | 0.000 | 0.000 | | 0.930 | 0.000 | | 0.002 | | | |
| No. Diff + | | 2 | 26 | | 16 | 12 | | 3 | 25 | | | |
| Average In | 1.0041 | 1.0808 | 1.0947 | 1.0041 | 1.0689 | 1.0892 | | | | | | |
| Average Out | 1.0041 | 1.0636 | 1.1209 | 1.0041 | 1.0695 | 1.0352 | 1.0041 | 1.0641 | 1.0671 | | | |
| t-test (paired) In | | | | 0.000 | | 0.262 | | | | | | |
| t-test (paired) Out | 0.000 | | 0.000 | 0.000 | | 0.048 | 0.000 | | 0.002 | | | |
| t-test (In v Out) | | | 0.134 | | | 0.059 | | | | | | |
| Panel D | QE3 - 01/06/12 – 08/05/13 | | | | | | | | | | | |
| (Out of sample) | APF days (0.0007) | | | | | | Own Issuance (0.0000) | | | | | |
| Average | 1.0048 | 0.9935 | 1.0210 | | | | 1.0048 | 0.9935 | 0.9932 | | | |
| t-test(paired) | | 0.001 | 0.000 | | | | | 0.001 | 0.001 | | | |
| No. Diff + | | 0 | 23 | | | | | 2 | 9 | | | |
| Average In | 1.0048 | 0.9891 | 1.0222 | | | | | | | | | |
| Average Out | 1.0048 | 0.9943 | 1.0207 | | | | 1.0048 | 0.9935 | 0.9932 | | | |
| t-test (paired) In | | 0.016 | 0.000 | | | | | | | | | |
| t-test (paired) Out | | 0.008 | 0.000 | | | | | 0.001 | 0.001 | | | |
| t-test (In v Out) | | | 0.697 | | | | | | | | | |

# Table 6: Regression tests of the effect of bond market events on bid-ask spreads

This table contains the estimated coefficients from the following regression

$$s_t = b_0 + b_1 s_{t-1} + b_2 s_{t-2} + b_3 s_{t-3} + b_4 s_{t-4} + b_5 s_{t-5} + b_6 OI_t + b_7 IS_t + b_8 OP_t + b_9 PS_t + b_{10} PA_t + b_{11} SH_t + b_{12} QEA_t + b_{13} MPC_t + b_{14} BR_t$$

where $s_t$is the end-of-day bid-ask spread on a bond return on day $t$, and the indicator variables take the value zero, unless the observations are on days that have (respectively) bond issuance, $IS_t$, bond purchases through the APF mechanism, $PA_t$ , own issuance, $OI_t$, own purchases, $OP_t$, purchases through the APF of close substitute bonds, $PS_t$, announcements relating to QE, $QEA_t$, meetings of the MPC, $MPC_t$, changes to the base rate, $BR_t$ , whereupon the indicator variables take the value one. The variable $SH_t$ is the percentage of the bond owned by the Bank of England (as a result of APF activity to that date) on day $t$. "No. Obs." is the number of observations, and $\overline{r_t}$ is the mean of the dependent variable. Estimated coefficients are statistically significant at the 1%, 5% and 10% levels when appended by ***,** and * respectively. The autoregressive coefficients are not reported to conserve space. Sub-samples exclude any variables that are zero for all bonds in the sub-sample

| | Panel A: Pre-QE1 - 02/01/04 – 10/03/09 | | | | | | Panel B: QE1 - 11/03/09 – 26/01/10 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | No. Obs. | $\overline{s_t}$ | $OI_t$ | $IS_t$ | $MPC_t$ | $BR_t$ | No. Obs. | $\overline{s_t}$ | $OI_t$ | $IS_t$ | $OP_t$ | $PS_t$ | $PA_t$ | $SH_t$ | $MPC_t$ | $QEA_t$ |
| TRSY 4.5% 2013 | 224 | 1.0617 | 0.0052 | 0.0020 | -0.0106* | 0.0008 | 209 | 0.9504 | -0.0036** | -0.0008 | -0.0028 | 0.0005 | -0.0066*** | 0.0027 | 0.0024 | -0.0109 |
| TRSY 8% 2013 | 220 | 0.0646 | 0.0091 | -0.0013 | -0.0169*** | 0.0217 | 222 | 0.0780 | 0.0000 | -0.0005 | -0.0032 | 0.0052*** | -0.0016 | -0.0013 | 0.0000 | 0.0003 |
| TRSY 2.25% 2014 | | | | | | | 203 | 0.0567 | 0.0039 | -0.0112 | 0.0090 | -0.0005 | -0.0043 | -0.0815 | 0.1388 | -0.1375 |
| TRSY 5% 2014 | 1282 | 0.0545 | -0.0122 | 0.0017 | -0.0073*** | 0.0055 | 222 | 0.0439 | 0.0189 | 0.0013 | -0.0111 | -0.0016 | 0.0020 | -0.0205 | 0.0074 | 0.0018 |
| TRSY 4.34% 2015 | 1242 | 0.0529 | -0.0124* | -0.0001 | -0.0035** | 0.0059 | 222 | 0.0483 | -0.0374** | -0.0061 | 0.0391*** | -0.0312*** | -0.0062 | -0.0213 | 0.0218 | -0.0319** |
| TRSY 8% 2015 | 1119 | 0.1600 | 0.0137 | -0.0058 | 0.0027 | -0.0334 | 222 | 0.0777 | 0.0000 | 0.0090 | -0.0097 | -0.0171 | -0.0100 | -0.2379 | -0.0271 | 0.0076 |
| TRSY 4% 2016 | 607 | 0.1006 | 0.0095 | -0.0126 | -0.0122* | -0.0201 | 216 | 0.0471 | -0.0320*** | 0.0017 | -0.0075 | 0.0128 | -0.0046 | -0.0702 | 0.0099 | 0.0110 |
| TRSY 8.75% 2017 | 1234 | 0.1804 | -0.0175 | -0.0149 | -0.0161 | -0.0422 | 222 | 0.0824 | 0.0000 | 0.0086 | 0.0019 | 0.0094 | -0.0076 | -0.1328 | -0.0067 | -0.0297** |
| TRSY 5% 2018 | 383 | 0.0956 | 0.0040 | -0.0120 | -0.0252** | 0.0088 | 216 | 0.0630 | 0.0000 | 0.0012 | -0.0009 | -0.0131 | 0.0088* | -0.0540* | 0.0022 | -0.0253*** |
| TRSY 4.5% 2019 | | | | | | | 216 | 0.0345 | -0.0344 | 0.0055 | 0.0055 | 0.0016 | -0.0042 | -0.0667 | -0.0038 | 0.0042 |
| TRSY 4.75% 2020 | 996 | 0.0707 | 0.0051 | -0.0062** | 0.0020 | -0.0118* | 222 | 0.0511 | 0.0410*** | -0.0024 | -0.0202** | -0.0079 | 0.0078 | -0.0341 | -0.0279*** | 0.0303* |
| TRSY 8% 2021 | 979 | 0.1309 | -0.0116 | -0.0007 | -0.0403*** | 0.0177 | 222 | 0.0827 | 0.0000 | -0.0109 | 0.0121 | -0.0022 | -0.0146 | -0.1449 | -0.0168 | -0.0385 |
| TRSY 4% 2022 | | | | | | | 210 | 0.0392 | -0.0030 | -0.0036 | 0.0307** | -0.0183 | -0.0047 | -0.0755** | 0.0193 | 0.0102 |
| TRSY 5% 2025 | 986 | 0.1678 | 0.0327 | -0.0006 | -0.0447*** | -0.0184 | 222 | 0.1005 | 0.0053 | 0.0091 | 0.0648 | -0.0522 | -0.0107 | -0.2851** | -0.0271 | -0.0347 |
| TRSY 4.25% 2027 | 223 | 0.1538 | -0.0127 | -0.0088 | -0.0237* | -0.0546 | 222 | 0.1228 | 0.0638*** | -0.0062 | 0.0072 | -0.0220 | 0.0022 | -0.1898*** | -0.0203 | 0.0090 |
| TRSY 6% 2028 | 945 | 0.1592 | -0.0045 | 0.0077 | -0.0249** | -0.0056 | 222 | 0.1344 | 0.0455** | -0.0065 | 0.0152 | 0.0069 | -0.0207 | -0.3971*** | -0.0079 | -0.0682 |
| TRSY 4.75% 2030 | | | | | | | 210 | 0.2810 | -0.0024 | 0.0034 | 0.0119 | -0.0102 | 0.0023 | -0.2699** | 0.0110 | 0.0430 |
| TRSY 4.25% 3032 | 1233 | 0.2700 | 0.0334 | -0.0143 | 0.0010 | -0.0571 | 222 | 0.2713 | 0.0164 | -0.0158 | -0.0092 | -0.0122 | 0.0157 | -0.4264*** | 0.0659 | -0.1140* |
| TRSY 4.25% 2036 | 1243 | 0.2560 | 0.0127 | -0.0275** | 0.0054 | -0.0645* | 222 | 0.1219 | 0.0000 | 0.0288 | -0.0251 | 0.0218 | -0.0140 | -0.3429* | -0.0028 | -0.0153 |
| TRSY 4.75% 2038 | 1216 | 0.0867 | -0.0101 | 0.0033 | 0.0027 | -0.0066 | 217 | 0.0984 | -0.0030 | -0.0287 | 0.0049 | -0.0150 | -0.0018 | -0.0745* | -0.0010 | -0.0059 |
| TRSY 4.25% 2039 | | | | | | | 209 | 0.0424 | -0.0137 | 0.0019 | -0.0073 | -0.0097 | 0.0039 | -0.0150 | 0.0687 | -0.1073** |
| TRSY 4.5% 2042 | 355 | 0.1013 | -0.0015 | -0.0025 | 0.0069 | -0.0270 | 211 | 0.1127 | 0.0000 | -0.0172 | 0.0181 | -0.0030 | -0.0203 | -0.6448* | -0.0282 | 0.0665*** |
| TRSY 4.25% 2046 | 509 | 0.1432 | -0.0619 | -0.0025 | 0.0025 | -0.0156 | 217 | 0.1451 | 0.0000 | 0.0266 | 0.0647** | 0.0212 | -0.0467* | -0.6424** | -0.0449 | 0.0878** |
| TRSY 4.25% 2049 | | | | | | | 196 | 0.1099 | 0.0131 | -0.0071 | 0.0220 | -0.0645 | 0.0876 | -0.3877* | 0.0926 | -0.0438 |
| TRSY 4.25% 2055 | 940 | 0.1420 | 0.0160 | -0.0042 | -0.0168* | -0.0253 | 207 | 0.2944 | 0.0000 | -0.0139 | 0.0006 | -0.0543 | 0.0548* | -0.1723 | -0.0151 | 0.0170 |

## Table 6: Regression tests of the effect of bond market events on bid-ask spreads (cont.)

| | Panel C: Post QE1 - 27/01/10 – 07/10/11 | | | | | | | Panel D: QE2&3 - 10/10/11 – 08/05/13 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | No. Obs. | $\bar{s_t}$ | $OI_t$ | $IS_t$ | $SH_t$ | $MPC_t$ | $QEA_t$ | No. Obs. | $\bar{s_t}$ | $OI_t$ | $IS_t$ | $OP_t$ | $PS_t$ | $PA_t$ | $SH_t$ | $MPC_t$ | $QEA_t$ |
| TRSY 4.5% 2013 | 379 | 1.0229 | -0.0103*** | 0.0025* | -0.0049 | -0.0045* | -0.0042 | | | | | | | | | | |
| TRSY 8% 2013 | 429 | 0.0578 | 0.0000 | -0.0017 | 0.0000 | 0.0009 | -0.0025 | | | | | | | | | | |
| TRSY 2.25% 2014 | 429 | 0.0855 | 0.1925*** | -0.0137 | 0.2918 | -0.0270* | 0.0106 | 400 | 0.0339 | 0.0789 | -0.0030 | 0.0000 | -0.0057 | 0.0008 | 1.4702 | 0.0018 | -0.0056 |
| TRSY 5% 2014 | 429 | 0.0895 | -0.0201 | 0.0008 | -0.1669* | -0.0367 | 0.0095 | 400 | 0.0290 | 0.0000 | -0.0019** | 0.0000 | 0.0014 | 0.0001 | 0.0752* | -0.0016* | 0.0009 |
| TRSY 2.75% 2015 | 414 | 0.1113 | 0.0158 | 0.0094 | -2.0388** | -0.0678* | 0.0575 | 400 | 0.0375 | 0.0613 | -0.0044 | 0.0109 | 0.0073 | -0.0045 | -0.5380** | -0.0008 | 0.0075 |
| TRSY 4.34% 2015 | 429 | 0.1204 | -0.0026 | -0.0220 | -0.5628*** | -0.0487* | 0.0255 | 394 | 0.0353 | 0.0392 | -0.0033 | 0.0080 | -0.0149 | -0.0025 | -0.2320** | 0.0002 | -0.0038 |
| TRSY 8% 2015 | 422 | 0.2692 | 0.0000 | -0.0114 | 0.0000 | -0.1824 | 0.1323 | 400 | 0.1097 | 0.0326*** | -0.0007 | -0.0049 | -0.0026 | -0.0005 | 0.0004 | -0.0034 | -0.0695*** |
| TRSY 2% 2016 | | | | | | | | 400 | 0.0360 | 0.0848 | -0.0032 | 0.0031 | 0.0067** | -0.0064* | -0.0554** | 0.0040 | -0.0020 |
| TRSY 4% 2016 | 429 | 0.1145 | -0.0368* | -0.0180 | -1.2114*** | -0.0445** | 0.0283 | 400 | 0.0356 | 0.0342 | 0.0015 | -0.0071** | 0.0047 | -0.0046 | -0.0259 | -0.0054** | 0.0129*** |
| TRSY 8.75% 2017 | 423 | 0.1436 | 0.0000 | -0.0100 | 0.0000 | -0.0756 | 0.0399 | 400 | 0.1037 | 0.0209* | 0.0015 | 0.0102** | -0.0052 | -0.0001 | -0.0072 | 0.0020 | -0.0365*** |
| TRSY 5% 2018 | 420 | 0.1293 | 0.0463* | -0.0265 | -0.6953*** | -0.0509** | -0.0047 | 400 | 0.0530 | 0.0236 | 0.0009 | 0.0016 | -0.0007 | -0.0009 | 0.0670 | -0.0041** | 0.0018 |
| TRSY 4.5% 2019 | 414 | 0.1189 | 0.0000 | -0.0226 | 0.0000 | -0.0472* | -0.0073 | 400 | 0.0350 | 0.0357 | -0.0054** | -0.0026 | -0.0048 | 0.0010 | -0.0322 | -0.0008 | 0.0171*** |
| TRSY 3.75% 2019 | 429 | 0.1016 | 0.0463*** | -0.0183 | -2.5745** | -0.0385* | 0.0435 | 400 | 0.0416 | 0.0612 | -0.0011 | 0.0016 | 0.0003 | -0.0055* | -0.0192 | -0.0023 | 0.0110** |
| TRSY 4.75% 2020 | 429 | 0.1277 | -0.0278 | -0.0210 | -0.2341*** | -0.0522** | 0.0238 | 400 | 0.0409 | 0.0450 | 0.0021 | 0.0168** | -0.0121 | 0.0039 | -0.2260** | -0.0074 | 0.0620 |
| TRSY 3.75% 2020 | | | | | | | | 400 | 0.0422 | 0.0369 | -0.0065 | 0.0177** | -0.0195** | 0.0075 | -0.3127*** | -0.0013 | -0.0116 |
| TRSY 8% 2021 | 422 | 0.2500 | 0.0000 | -0.0207 | 0.0000 | -0.1897 | 0.1715 | 400 | 0.0461 | 0.0371 | -0.0097* | 0.0000 | 0.0016 | -0.0012 | 1.1355* | -0.0031 | 0.0777*** |
| TRSY 3.75% 2021 | | | | | | | | 400 | 0.0353 | -0.0002 | -0.0007 | -0.0006 | 0.0004 | -0.0004 | -0.0043 | -0.0010*** | 0.0001 |
| TRSY 4% 2022 | 429 | 0.1126 | -0.0348 | -0.0067 | -0.4370*** | -0.0365 | 0.0151 | 400 | 0.0483 | 0.0263 | -0.0005 | 0.0102 | -0.0070 | 0.0028 | -0.0371 | -0.0005 | 0.0587 |
| TRSY 5% 2025 | 429 | 0.1642 | -0.3970*** | -0.0157 | -0.0041 | -0.0417** | 0.0496 | 400 | 0.0687 | 0.0118 | -0.0053 | 0.0055 | 0.0002 | -0.0019 | -0.1518*** | 0.0009 | 0.0324 |
| TRSY 4.25% 2027 | 422 | 0.2241 | -0.0177 | -0.0054 | -0.1346 | -0.1396 | 0.1196 | 400 | 0.0751 | -0.0164*** | 0.0005 | 0.0084 | 0.0090* | -0.0037 | -0.0469* | 0.0051 | 0.0300 |
| TRSY 6% 2028 | 422 | 0.2371 | -0.0007 | -0.0130 | -1.1632* | -0.1269 | 0.1227 | 400 | 0.0649 | -0.0083 | -0.0009 | 0.0011 | -0.0043 | 0.0037 | -0.0330 | 0.0070 | 0.0478* |
| TRSY 4.75% 2030 | 413 | 0.2631 | 0.0354 | -0.0181 | -0.8008 | -0.1389 | 0.1629 | 400 | 0.0766 | 0.0032 | 0.0005 | 0.0119 | -0.0108 | 0.0051 | -0.1373** | 0.0128* | 0.0460 |
| TRSY 4.25% 3032 | 422 | 0.2615 | -0.0109 | -0.0111 | -1.1579 | -0.1244 | 0.1188 | 400 | 0.0821 | 0.0035 | 0.0011 | 0.0023 | -0.0097 | 0.0086** | -0.1254** | 0.0025 | 0.0051 |
| TRSY 4.5% 2034 | 429 | 0.1489 | -0.0258 | -0.0129 | -0.5055** | -0.0565** | 0.0292 | 400 | 0.0778 | 0.0064 | 0.0032 | 0.0021 | -0.0022 | 0.0012 | -0.0812 | 0.0055 | 0.0048 |
| TRSY 4.25% 2036 | 429 | 0.1691 | -0.7352*** | -0.0189 | -3.3055 | -0.0627** | 0.0783 | 394 | 0.0820 | 0.0397 | -0.0003 | -0.0084 | 0.0015 | 0.0042 | -0.1643*** | 0.0132* | 0.0473 |
| TRSY 4.75% 2038 | 422 | 0.2362 | -0.0269 | -0.0066 | -2.6988* | -0.1581* | 0.1390 | 400 | 0.0872 | 0.0273 | -0.0027 | 0.0114 | -0.0080 | 0.0016 | -0.4938*** | 0.0061 | 0.0029 |
| TRSY 4.25% 2039 | 429 | 0.1599 | 0.0010 | -0.0112 | -0.6298*** | -0.0327 | -0.0065 | 400 | 0.0925 | 0.0184 | -0.0080*** | -0.0069 | 0.0017 | 0.0009 | -0.1053** | 0.0028 | 0.0353 |
| TRSY 4.25% 2040 | | | | | | | | 400 | 0.0947 | 0.0022 | -0.0008 | -0.0044 | 0.0072 | 0.0017 | -0.0704*** | -0.0015 | 0.0479** |
| TRSY 4.5% 2042 | 422 | 0.2530 | 0.0000 | -0.0127 | 0.0000 | -0.1308 | 0.1411 | 400 | 0.1227 | 0.0120** | -0.0025 | -0.0019 | 0.0018 | 0.0016 | -0.0918*** | -0.0016 | 0.0086* |
| TRSY 4.25% 2046 | 417 | 0.2579 | -0.0313 | 0.0012 | -1.6841* | -0.1263 | 0.1089 | 400 | 0.1323 | 0.0090 | 0.0005 | 0.0042 | -0.0032 | -0.0021 | -0.1219*** | -0.0013 | -0.0042 |
| TRSY 4.25% 2049 | 417 | 0.2492 | -0.0274 | 0.0122 | -2.7937** | -0.0865 | 0.0044 | 400 | 0.1432 | 0.0035 | 0.0029 | 0.0047 | -0.0043 | 0.0024 | -0.0839*** | 0.0035 | -0.0095 |
| TRSY 4.25% 2055 | 417 | 0.3563 | -0.3243*** | -0.0119 | -2.1108** | -0.1144 | 0.0299 | 395 | 0.1704 | 0.0017 | 0.0032 | -0.0010 | -0.0038 | 0.0029 | -0.0713** | 0.0005 | -0.0081 |
| TRSY 4% 2060 | 323 | 0.1521 | -0.0159 | 0.0116 | -0.3535 | 0.0167 | -0.0812 | 395 | 0.1757 | 0.0006 | 0.0012 | 0.0042 | -0.0055 | 0.0026 | -0.0183 | 0.0056 | -0.0126*** |

Figure 1: Holdings of Individual Gilts by the Bank of England

The box plots shows the distribution of ownership shares of individual gilts held by the Bank of England at the end of each of the sub-periods indicated. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles. (Source: Bank of England and the UK DMO).

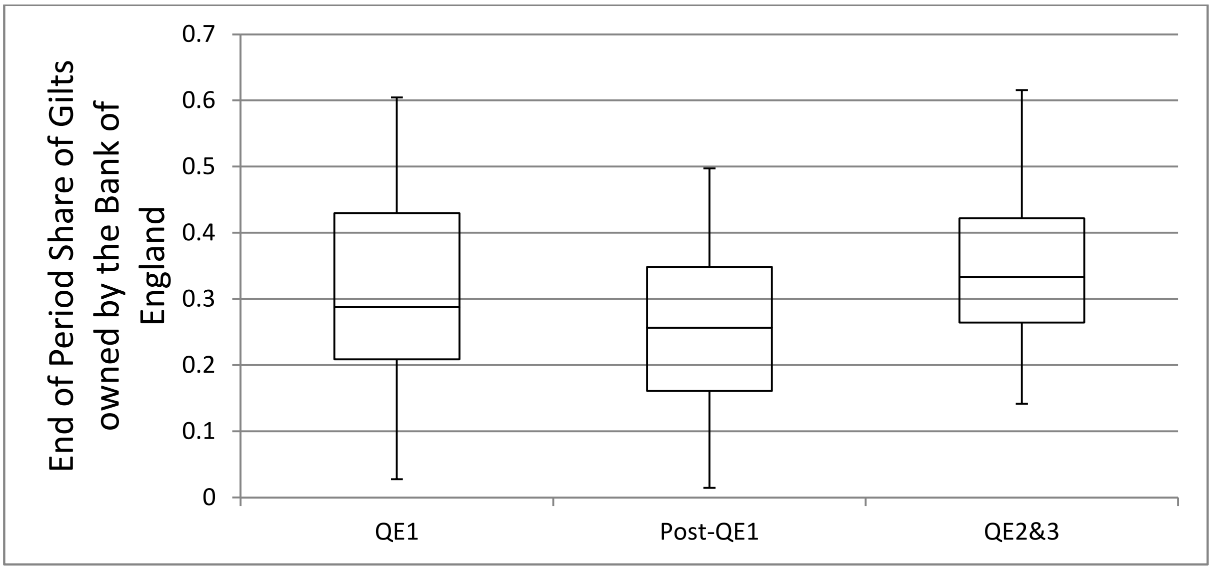



Figure 2: Total Holdings of Gilts by the Bank of England

This graph shows the total size of the gilt market, the growth in market (cumulative net issuance), and the shares of the market owned by the Bank of England between 2004Q1 and 2013Q2. (Source: Bank of England and the UK DMO).

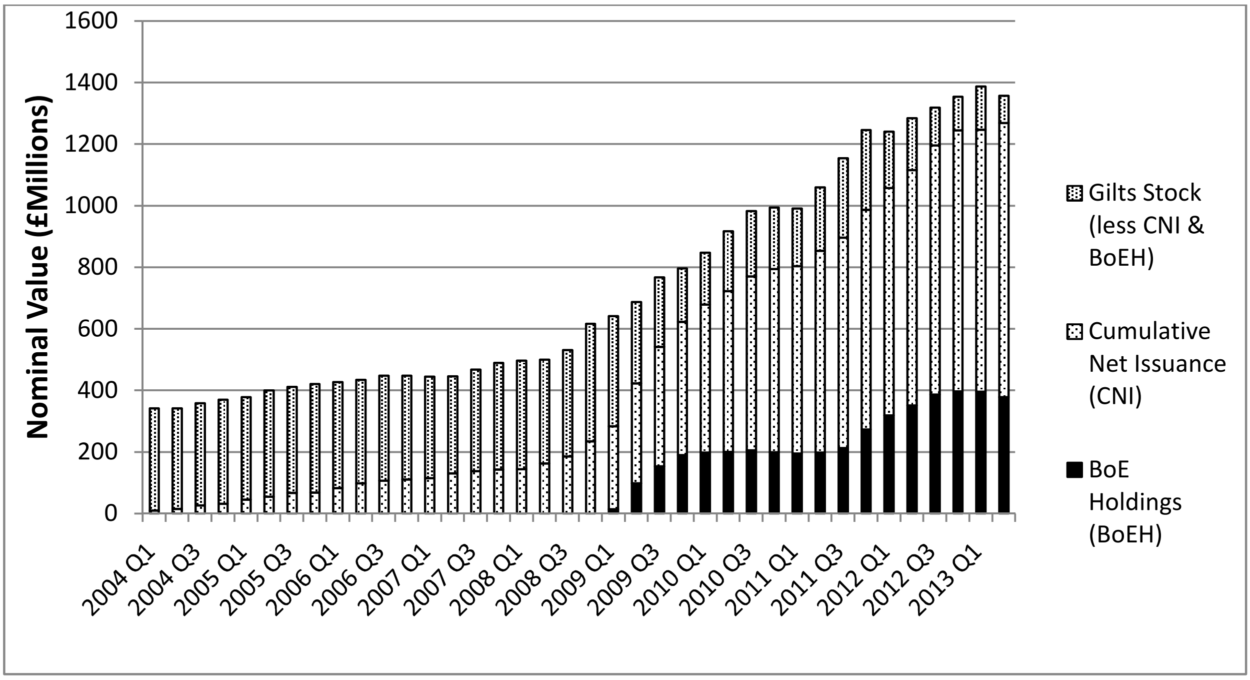


Figure 3: Distribution of mean returns to gilts

The box plots represent the distribution of mean returns (capital change only) of gilts in each of the sub-samples. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles.

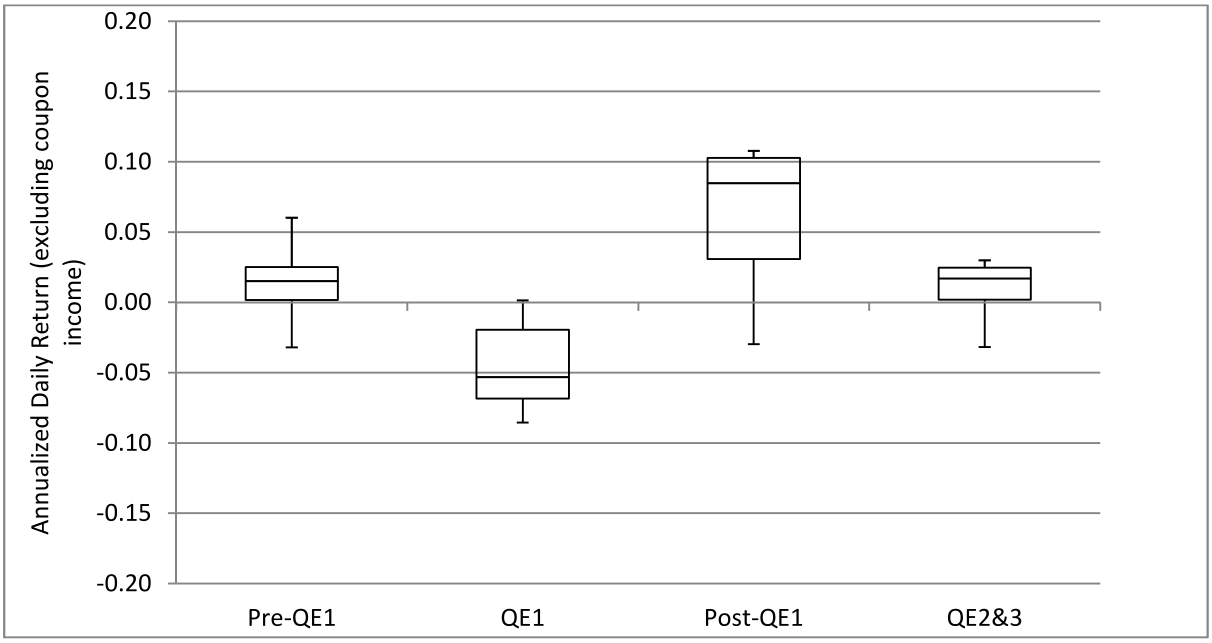



Figure 4: Distribution of standard deviation of returns to gilts

The box plots represent the distribution of standard deviations of returns of gilts in each of the sub-samples. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles.

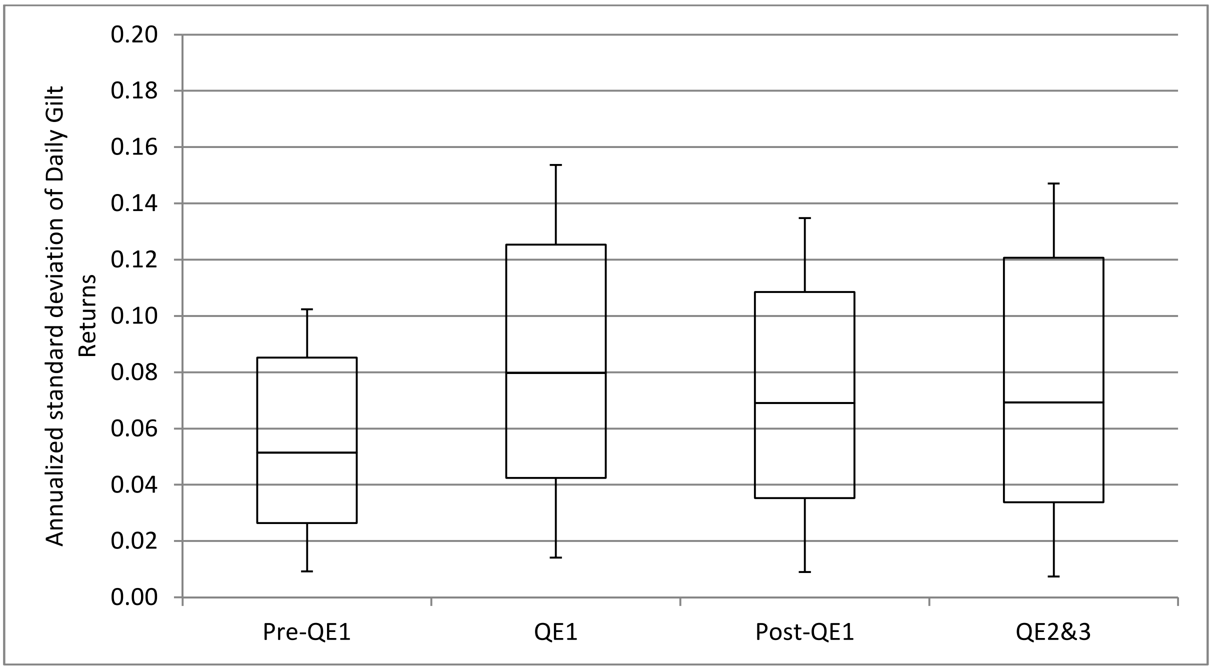


Figure 5: Distribution of skewness of returns to gilts

The box plots represent the distribution of skewness of returns of gilts in each of the sub-samples. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles.

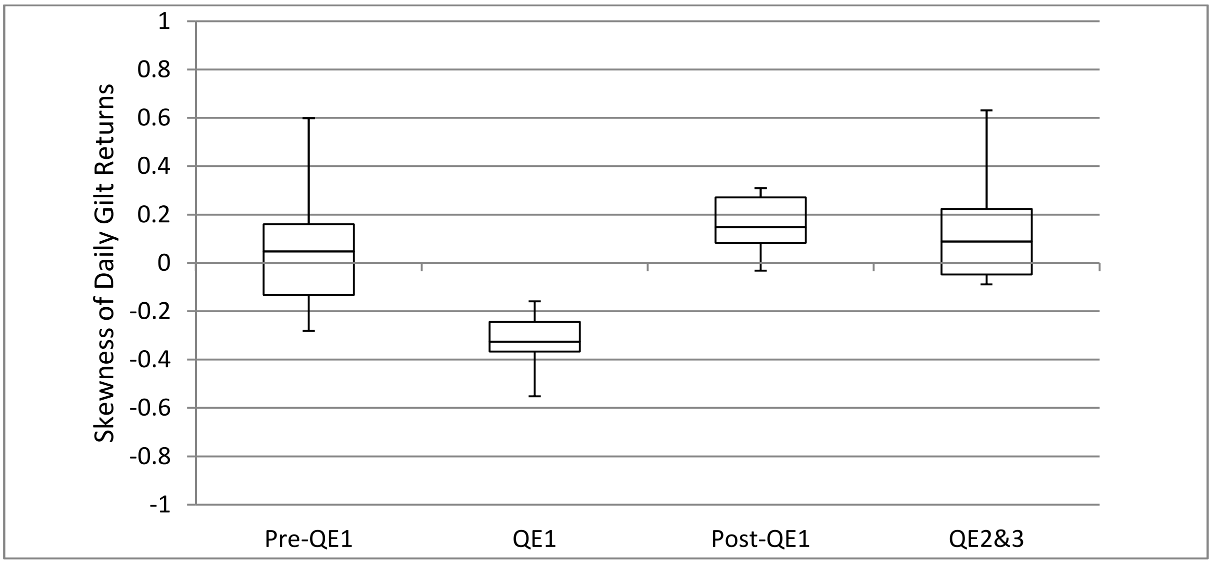



Figure 6: Distribution of first-order autocorrelation of returns to gilts

The box plots represent the distribution of the coefficients of first-order autocorrelation of the returns to the gilts in the sub-samples indicated. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles.

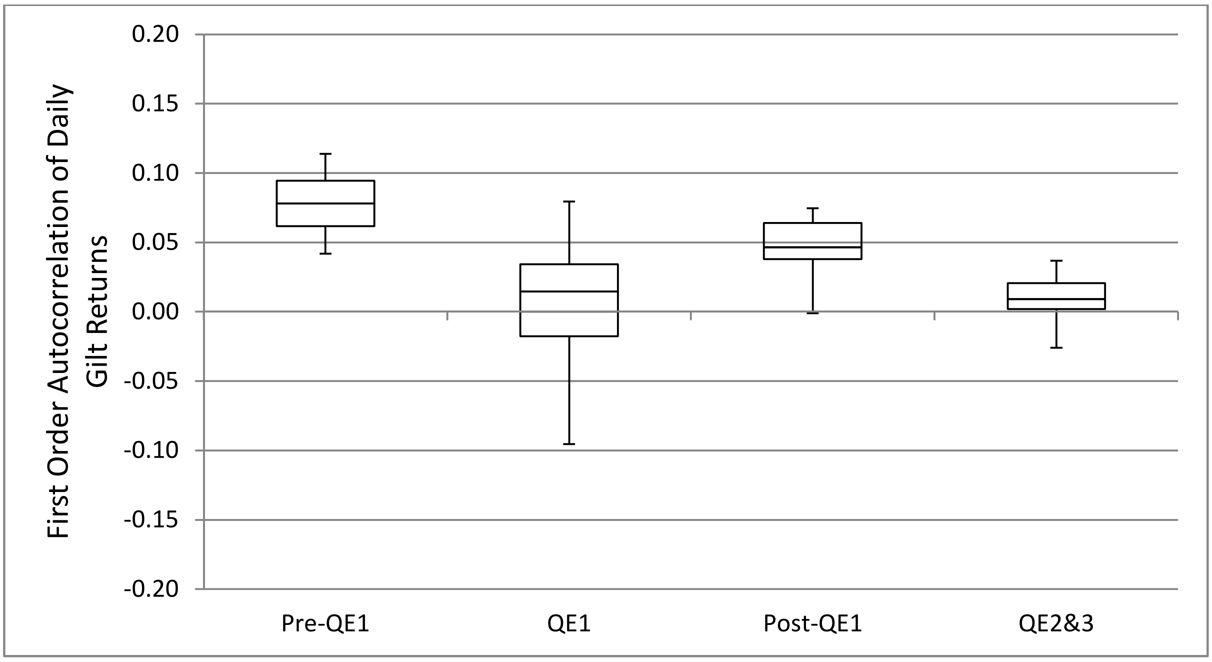


Figure 7: Distribution of second-order autocorrelation of returns to gilts

The box plots represent the distribution of the coefficients of second-order autocorrelation of the returns to the gilts in the sub-samples indicated. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles.

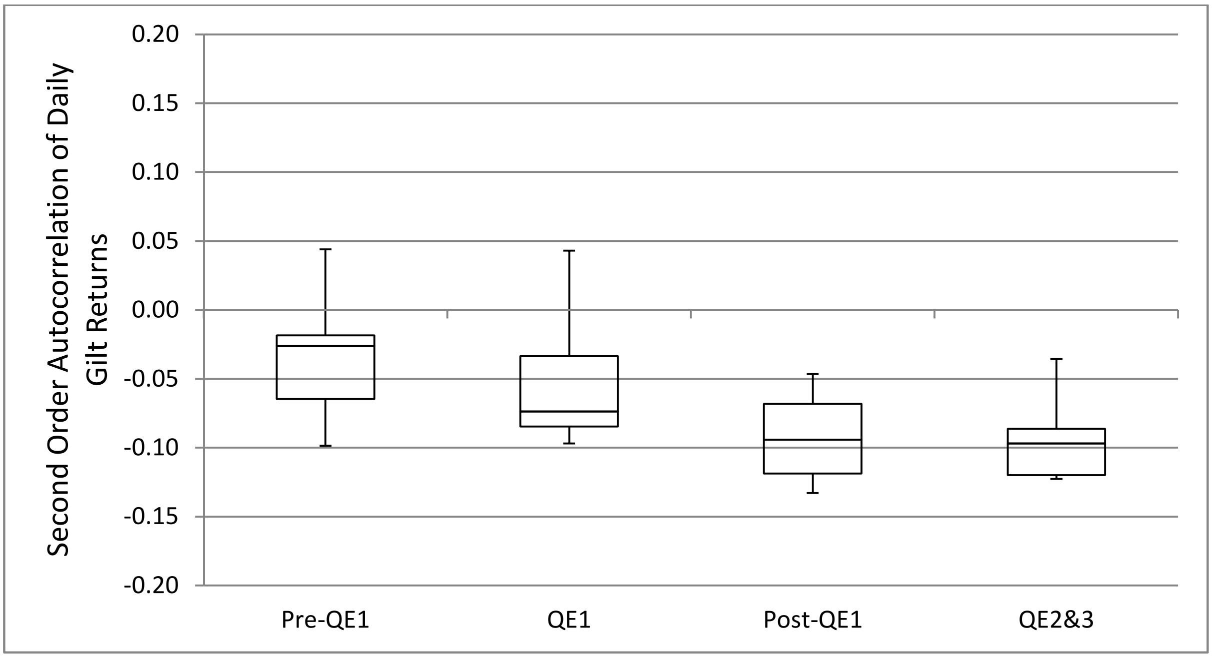



Figure 8: Distribution of third-order autocorrelation of returns to gilts

The box plots represent the distribution of the coefficients of third-order autocorrelation of the returns to the gilts in the sub-samples indicated. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles.

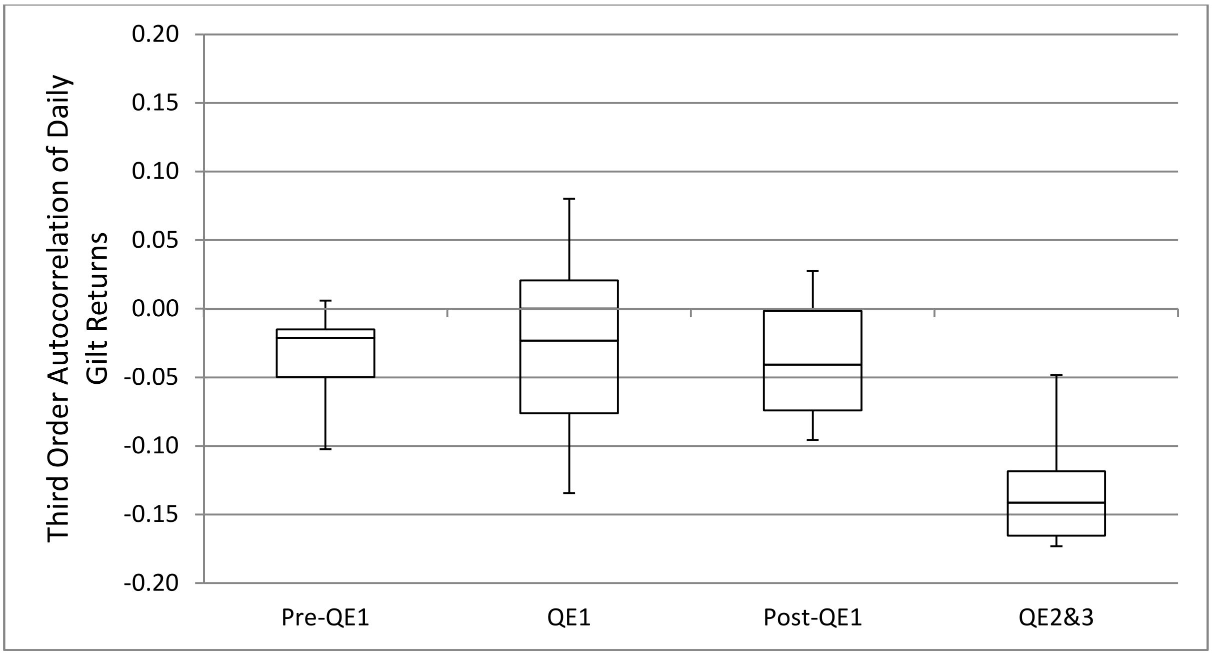


Figure 9: Gilt Issuance by day of the week

This figure shows the distribution of gilt issuance across the days of the week for each of the sub-samples. The bars are ratio of the number of times that weekday was used for issuance to the total number of that weekday in the sub-sample. For example, over 45 percent of all Wednesdays during the QE1 phase experienced gilt issuance. (Source: UK DMO)

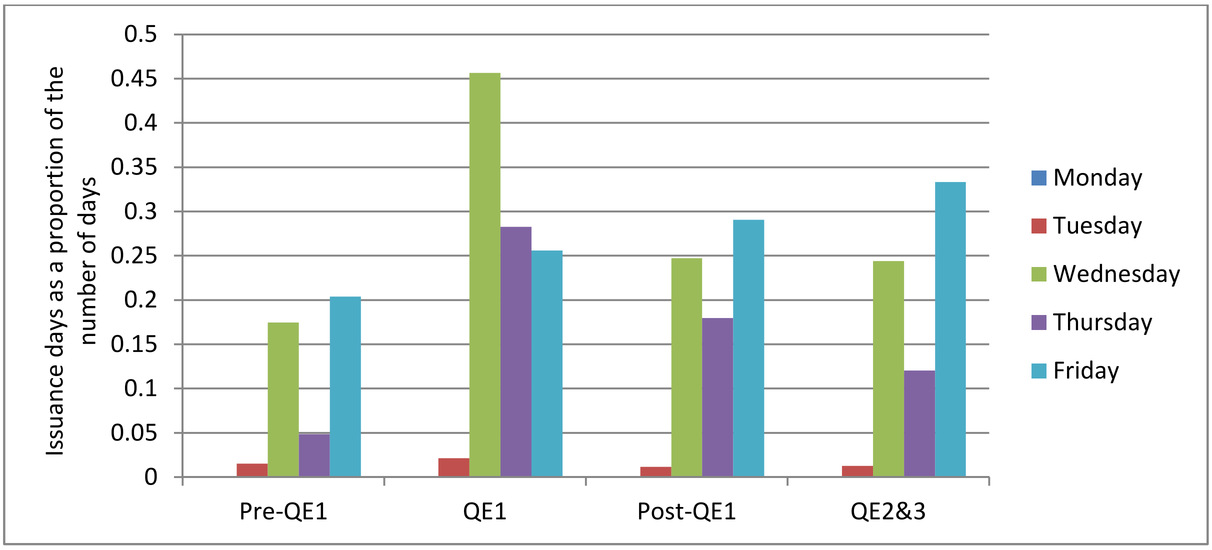



Figure 10: Gilt Purchase Auctions by day of the week

This figure shows the distribution of gilt purchase auctions across the days of the week for each of the sub-samples. The bars are ratio of the number of times that weekday was used for purchase auctions to the total number of that weekday in the sub-sample. For example, almost 80 percent of all Wednesdays during the QE1 phase experienced gilt purchase auctions. (Source: Bank of England).

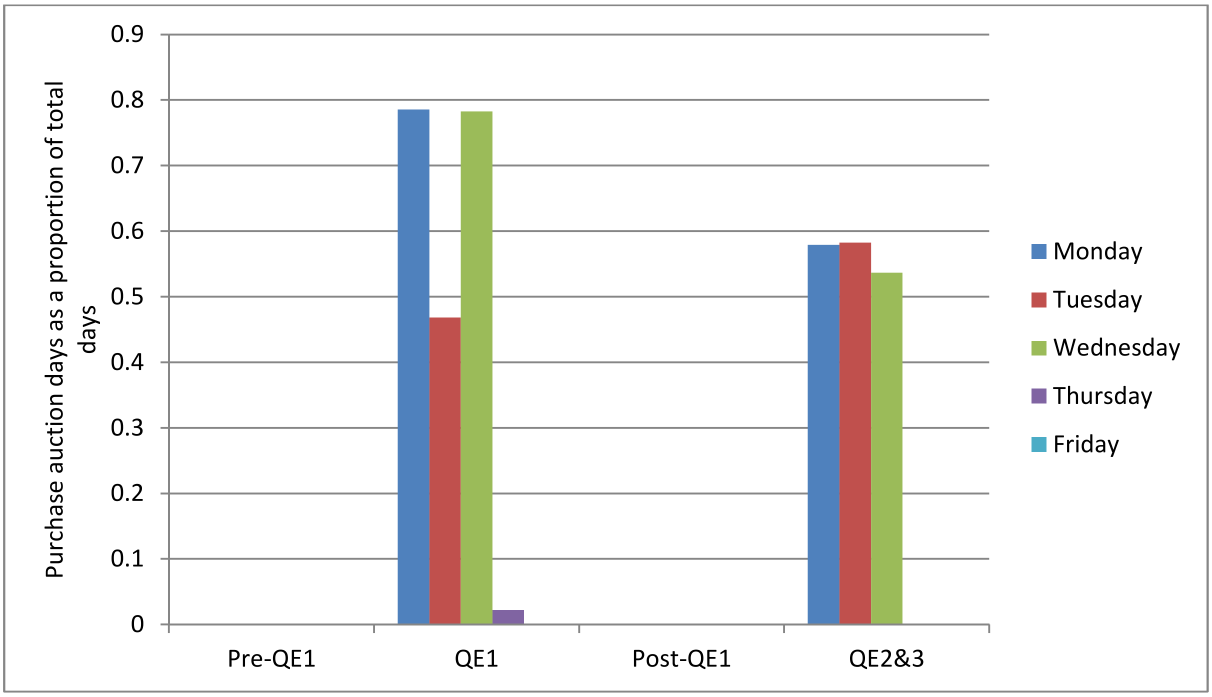


Figure 11: Autocorrelation-based Trading Rule Payoffs

The box plots show the distribution of terminal payoffs from applying either passive or active trading strategies (based upon significant return autocorrelation) to individual gilts in the sub-samples indicated. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles. The terminal payoff from a risk-free investment is indicated with a diamond. In the pre-QE1 (post-QE1) [QE2&3] periods, significant return autocorrelation was found at lag 1 (2) [3].

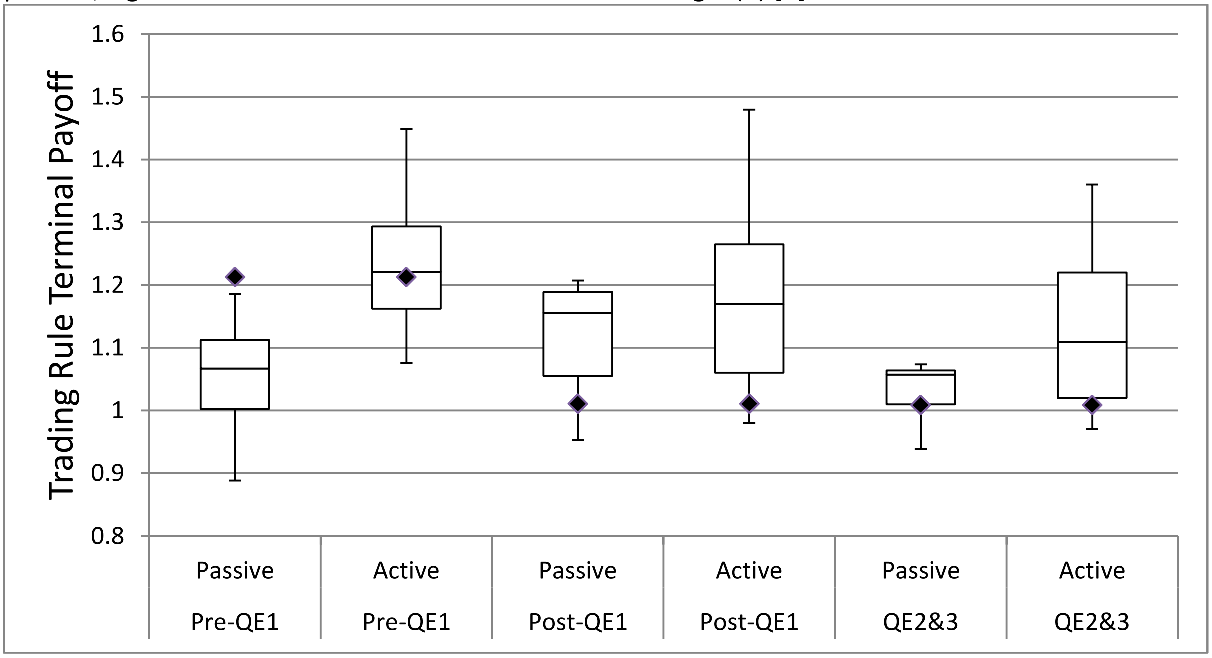



Figure 12: Distribution of Bid-Ask Spreads of Gilts

The box plots shows the distribution of gilt bid-ask spreads collected at the close of the day from Thomson Reuters Eikon for all gilts across all of the days in each of the sub-samples. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles.

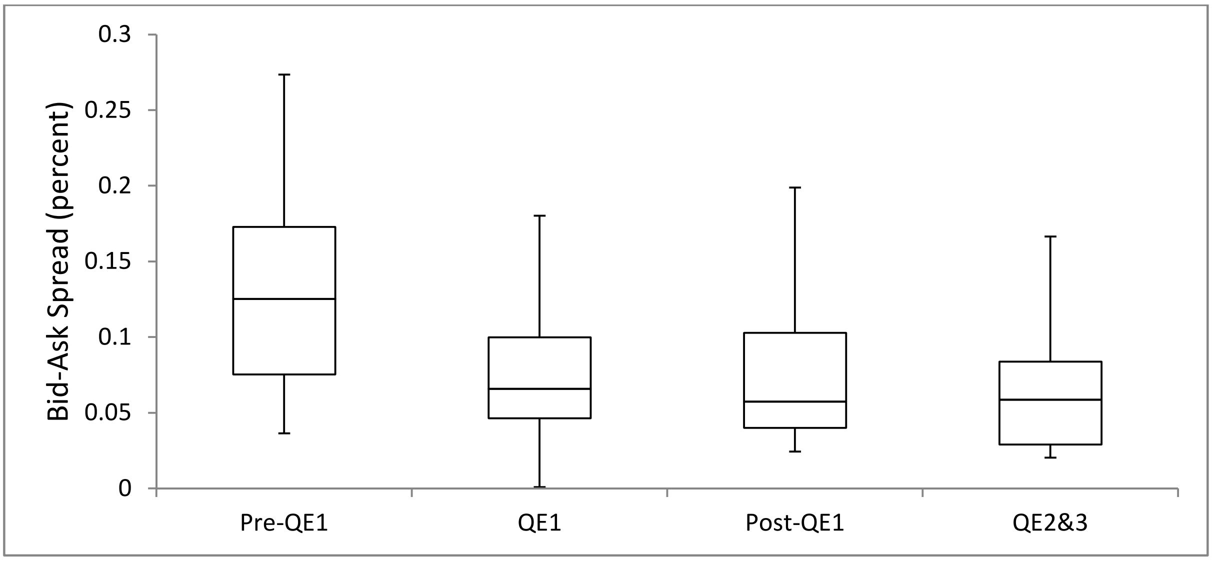
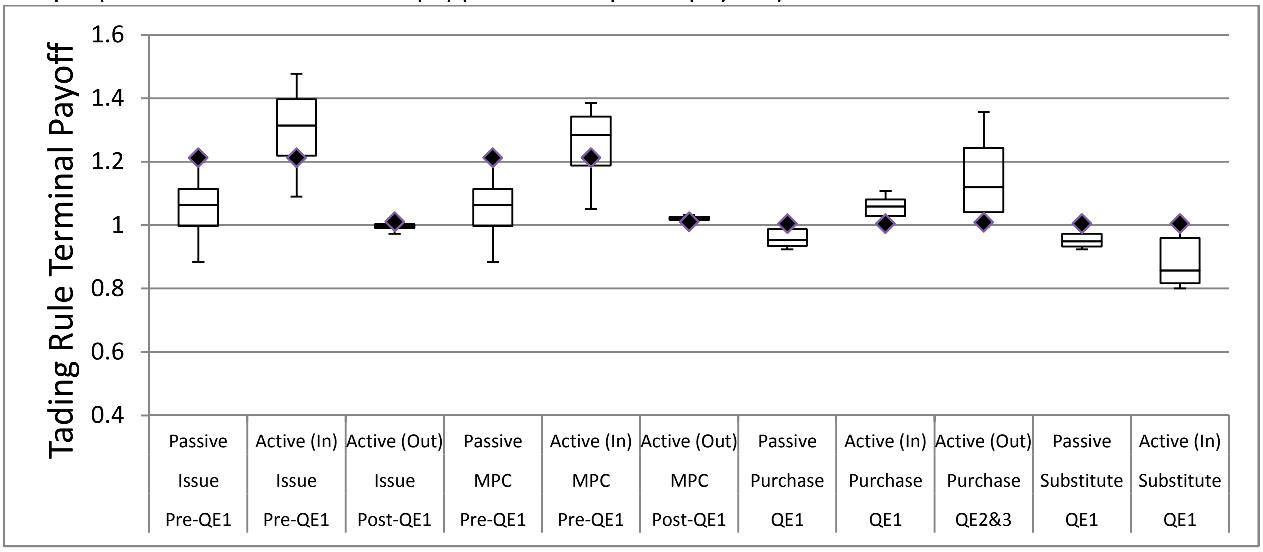
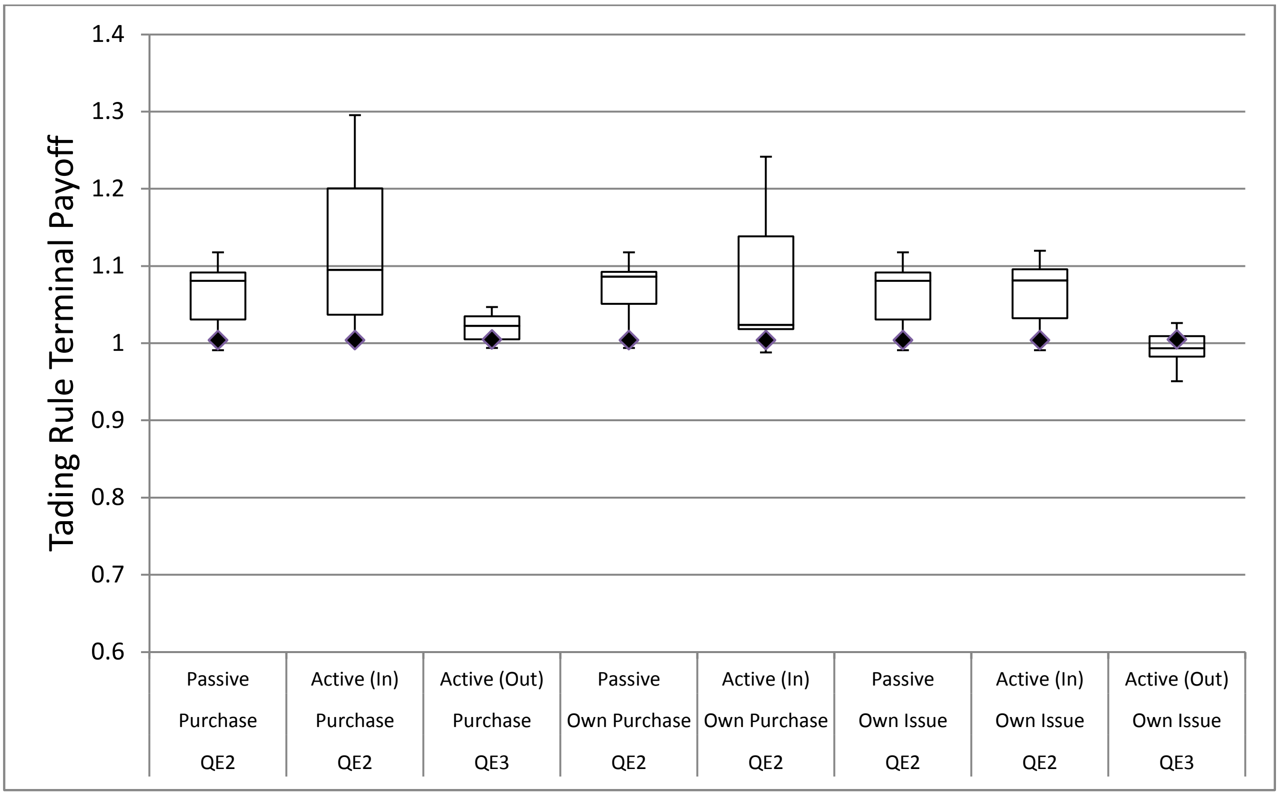


Figure 13: Event-based Trading Rule Payoffs

The box plots show the distribution of terminal payoffs from applying either passive or active trading strategies (based upon significant event dummies) to individual gilts in the sub-samples indicated. “Issue” events are days of any new issues. “MPC” are days of MPC meetings. “Purchase” events are days of any APF purchases. “Substitute” are days on which close substitute bonds are purchased. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles. The terminal payoff from a risk-free investment is indicated with a diamond. Active (In) plots are the in-sample (time series) results (the ex-post payoffs from a rule identified using data for the same sample period). Active (Out) plots are the out-of-sample (time series) results from applying the same rule to a later sub-sample (in cases where the Active (In) produced superior payoffs).



## Appendix

Table A.1: Summary Statistics

This table contains summary statistics for daily returns (daily change in log clean price) for the gilts listed for all trading days within the particular sub-sample. Quartile refers to the quartile of the returns distribution. Skew is the skewness of returns. Kurtosis is excess kurtosis. Zeros counts the number of zero daily returns in the period. No. Obs. is the number of observations available for the bond within the sample. This is less than the maximum due to initial issue or maturity arising within the sample period.

| | Panel A: Pre-QE1 - 02/01/04-10/03/09 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | No. Obs. | Mean | Std. Dev. | Minimum | Quartile 1 | Median | Quartile 3 | Maximum | Skewness | Kurtosis | Zeros |
| TRSY 4.5% 2007 | 775 | <0.00001 | 0.00058 | -0.00321 | -0.00020 | 0.00000 | 0.00020 | 0.00290 | -0.281 | 5.222 | 158 |
| TRSY 8.5% 2007 | 892 | -0.00013 | 0.00064 | -0.00349 | -0.00038 | -0.00010 | 0.00010 | 0.00408 | -0.004 | 6.080 | 80 |
| TRSY 7.25% 2007 | 995 | -0.00009 | 0.00072 | -0.00387 | -0.00037 | -0.00010 | 0.00019 | 0.00466 | -0.004 | 6.087 | 109 |
| TRSY 5% 2008 | 1057 | -0.00001 | 0.00078 | -0.00405 | -0.00030 | 0.00000 | 0.00030 | 0.00512 | -0.065 | 5.926 | 136 |
| TRSY 4% 2009 | 1309 | 0.00002 | 0.00100 | -0.00506 | -0.00041 | 0.00000 | 0.00052 | 0.00618 | -0.090 | 4.122 | 87 |
| TRSY 5.75% 2009 | 1311 | -0.00001 | 0.00126 | -0.00562 | -0.00068 | 0.00000 | 0.00069 | 0.00662 | -0.136 | 2.245 | 39 |
| TRSY 4.75% 2010 | 1087 | 0.00004 | 0.00136 | -0.00638 | -0.00070 | 0.00000 | 0.00090 | 0.00591 | -0.167 | 1.498 | 31 |
| TRSY 6.25% 2010 | 1311 | 0.00000 | 0.00164 | -0.00717 | -0.00092 | 0.00000 | 0.00101 | 0.00733 | -0.135 | 1.788 | 36 |
| TRSY 4.25% 2011 | 843 | 0.00008 | 0.00169 | -0.00799 | -0.00083 | 0.00010 | 0.00114 | 0.00713 | -0.176 | 1.835 | 20 |
| CVSN 9% 2011 | 1311 | -0.00005 | 0.00180 | -0.00841 | -0.00106 | 0.00000 | 0.00105 | 0.00759 | -0.148 | 1.676 | 28 |
| TRSY 5% 2012 | 1311 | 0.00006 | 0.00213 | -0.00974 | -0.00119 | 0.00010 | 0.00136 | 0.00889 | -0.129 | 1.592 | 23 |
| TRSY 5.25% 2012 | 500 | 0.00017 | 0.00251 | -0.00997 | -0.00120 | 0.00018 | 0.00174 | 0.00948 | -0.201 | 1.490 | 9 |
| TRSY 4.5% 2013 | 256 | 0.00030 | 0.00345 | -0.01142 | -0.00167 | 0.00053 | 0.00234 | 0.01137 | -0.255 | 0.935 | 3 |
| TRSY 8% 2013 | 1311 | 0.00000 | 0.00247 | -0.01045 | -0.00145 | 0.00000 | 0.00159 | 0.01157 | -0.039 | 1.575 | 17 |
| TRSY 5% 2014 | 1311 | 0.00009 | 0.00291 | -0.01134 | -0.00165 | 0.00010 | 0.00192 | 0.01106 | -0.025 | 1.198 | 18 |
| TRSY 4.34% 2015 | 1311 | 0.00011 | 0.00324 | -0.01229 | -0.00181 | 0.00010 | 0.00210 | 0.01665 | 0.047 | 1.612 | 17 |
| TRSY 8% 2015 | 1311 | 0.00004 | 0.00309 | -0.01181 | -0.00178 | 0.00000 | 0.00191 | 0.01857 | 0.139 | 2.283 | 17 |
| TRSY 4% 2016 | 769 | 0.00013 | 0.00389 | -0.01337 | -0.00211 | 0.00000 | 0.00247 | 0.02022 | 0.225 | 2.380 | 10 |
| TRSY 8.75% 2017 | 1311 | 0.00003 | 0.00349 | -0.01326 | -0.00195 | 0.00000 | 0.00212 | 0.02317 | 0.214 | 3.001 | 10 |
| TRSY 5% 2018 | 454 | 0.00038 | 0.00503 | -0.01510 | -0.00240 | 0.00049 | 0.00355 | 0.02317 | 0.118 | 1.795 | 6 |
| TRSY 4.75% 2020 | 1004 | 0.00013 | 0.00436 | -0.01597 | -0.00242 | 0.00010 | 0.00285 | 0.02385 | 0.164 | 2.192 | 7 |
| TRSY 8% 2021 | 1311 | 0.00006 | 0.00404 | -0.01546 | -0.00222 | 0.00008 | 0.00251 | 0.02346 | 0.126 | 2.330 | 6 |
| TRSY 5% 2025 | 1311 | 0.00008 | 0.00517 | -0.02310 | -0.00267 | 0.00018 | 0.00312 | 0.05156 | 0.957 | 11.881 | 11 |
| TRSY 4.25% 2027 | 635 | 0.00009 | 0.00689 | -0.02623 | -0.00343 | 0.00000 | 0.00380 | 0.06228 | 1.427 | 14.683 | 9 |
| TRSY 6% 2028 | 1311 | 0.00007 | 0.00557 | -0.02508 | -0.00294 | 0.00017 | 0.00336 | 0.05836 | 1.045 | 13.438 | 7 |
| TRSY 4.25% 3032 | 1311 | 0.00009 | 0.00643 | -0.02962 | -0.00330 | 0.00020 | 0.00386 | 0.06691 | 0.925 | 12.485 | 17 |
| TRSY 4.25% 2036 | 1311 | 0.00008 | 0.00671 | -0.03192 | -0.00353 | 0.00020 | 0.00414 | 0.05472 | 0.298 | 5.991 | 11 |
| TRSY 4.75% 2038 | 1242 | 0.00009 | 0.00685 | -0.03127 | -0.00378 | 0.00028 | 0.00413 | 0.05074 | 0.157 | 4.871 | 12 |
| TRSY 4.25% 2042 | 447 | 0.00014 | 0.00953 | -0.03353 | -0.00530 | 0.00020 | 0.00558 | 0.05147 | 0.088 | 3.168 | 2 |
| TRSY 4.25% 2046 | 716 | -0.00001 | 0.00870 | -0.03585 | -0.00497 | 0.00000 | 0.00481 | 0.05485 | 0.156 | 4.155 | 9 |
| TRSY 4.25% 2055 | 958 | 0.00003 | 0.00890 | -0.03947 | -0.00521 | 0.00005 | 0.00512 | 0.05784 | 0.127 | 4.097 | 4 |

| | Panel B: QE1 - 11/03/09 – 26/01/10 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | Nobs | Mean | Std Dev | Min | Q1 | Median | Q3 | Max | Skew | Excess Kurt | Zeros |
| TRSY 4.25% 2011 | 222 | -0.00008 | 0.00089 | -0.00378 | -0.00057 | -0.00005 | 0.00048 | 0.00266 | -0.350 | 1.404 | 13 |
| CVSN 9% 2011 | 222 | -0.00023 | 0.00109 | -0.00632 | -0.00087 | -0.00017 | 0.00043 | 0.00293 | -0.850 | 4.058 | 11 |
| TRSY 3.25% 2011 | 222 | -0.00001 | 0.00131 | -0.00539 | -0.00068 | 0.00010 | 0.00086 | 0.00357 | -0.454 | 1.190 | 6 |
| TRSY 5% 2012 | 222 | -0.00006 | 0.00141 | -0.00563 | -0.00093 | 0.00009 | 0.00083 | 0.00334 | -0.423 | 0.839 | 5 |
| TRSY 5.25% 2012 | 222 | -0.00007 | 0.00154 | -0.00621 | -0.00119 | 0.00005 | 0.00092 | 0.00339 | -0.468 | 0.787 | 7 |
| TRSY 4.5% 2013 | 222 | -0.00008 | 0.00212 | -0.00849 | -0.00159 | 0.00009 | 0.00132 | 0.00679 | -0.342 | 1.728 | 7 |
| TRSY 8% 2013 | 222 | -0.00016 | 0.00217 | -0.00834 | -0.00166 | 0.00000 | 0.00133 | 0.00723 | -0.182 | 0.846 | 5 |
| TRSY 2.25% 2014 | 214 | 0.00001 | 0.00263 | -0.01046 | -0.00175 | 0.00000 | 0.00182 | 0.00787 | -0.183 | 0.848 | 6 |
| TRSY 5% 2014 | 222 | -0.00019 | 0.00279 | -0.01078 | -0.00194 | 0.00000 | 0.00162 | 0.00745 | -0.385 | 0.727 | 5 |
| TRSY 4.34% 2015 | 222 | -0.00022 | 0.00337 | -0.01220 | -0.00221 | -0.00009 | 0.00186 | 0.00910 | -0.442 | 0.939 | 0 |
| TRSY 8% 2015 | 222 | -0.00029 | 0.00326 | -0.01205 | -0.00219 | -0.00030 | 0.00177 | 0.00867 | -0.346 | 0.637 | 3 |
| TRSY 4% 2016 | 222 | -0.00024 | 0.00392 | -0.01376 | -0.00278 | -0.00009 | 0.00220 | 0.01122 | -0.283 | 0.644 | 1 |
| TRSY 8.75% 2017 | 222 | -0.00031 | 0.00408 | -0.01630 | -0.00293 | -0.00022 | 0.00239 | 0.01180 | -0.272 | 1.007 | 2 |
| TRSY 5% 2018 | 222 | -0.00030 | 0.00457 | -0.01865 | -0.00326 | -0.00027 | 0.00284 | 0.01188 | -0.321 | 0.925 | 0 |
| TRSY 4.5% 2019 | 222 | -0.00030 | 0.00500 | -0.01927 | -0.00342 | 0.00000 | 0.00284 | 0.01181 | -0.322 | 0.681 | 8 |
| TRSY 4.75% 2020 | 222 | -0.00028 | 0.00510 | -0.01952 | -0.00359 | -0.00009 | 0.00344 | 0.01243 | -0.313 | 0.568 | 1 |
| TRSY 8% 2021 | 222 | -0.00035 | 0.00505 | -0.01934 | -0.00377 | -0.00032 | 0.00339 | 0.01259 | -0.235 | 0.488 | 0 |
| TRSY 4% 2022 | 222 | -0.00024 | 0.00592 | -0.02324 | -0.00404 | 0.00020 | 0.00413 | 0.01403 | -0.345 | 0.610 | 2 |
| TRSY 5% 2025 | 222 | -0.00029 | 0.00629 | -0.02649 | -0.00420 | 0.00032 | 0.00421 | 0.02047 | -0.344 | 1.523 | 1 |
| TRSY 4.25% 2027 | 222 | -0.00028 | 0.00725 | -0.03082 | -0.00486 | 0.00030 | 0.00494 | 0.02508 | -0.304 | 1.672 | 3 |
| TRSY 6% 2028 | 222 | -0.00027 | 0.00709 | -0.02990 | -0.00451 | 0.00044 | 0.00447 | 0.02405 | -0.330 | 1.591 | 4 |
| TRSY 4.75% 2030 | 222 | -0.00027 | 0.00762 | -0.03210 | -0.00467 | 0.00019 | 0.00496 | 0.02349 | -0.394 | 1.518 | 4 |
| TRSY 4.25% 3032 | 222 | -0.00025 | 0.00798 | -0.03401 | -0.00521 | 0.00048 | 0.00527 | 0.02471 | -0.371 | 1.511 | 0 |
| TRSY 4.25% 2036 | 222 | -0.00022 | 0.00819 | -0.03621 | -0.00535 | -0.00010 | 0.00497 | 0.02376 | -0.355 | 1.375 | 1 |
| TRSY 4.75% 2038 | 222 | -0.00021 | 0.00824 | -0.03474 | -0.00565 | 0.00036 | 0.00496 | 0.02428 | -0.289 | 1.113 | 0 |
| TRSY 4.25% 2039 | 222 | -0.00012 | 0.00839 | -0.03011 | -0.00571 | 0.00010 | 0.00529 | 0.02498 | -0.159 | 0.551 | 0 |
| TRSY 4.25% 2042 | 222 | -0.00010 | 0.00870 | -0.03399 | -0.00591 | 0.00020 | 0.00539 | 0.02564 | -0.213 | 0.774 | 2 |
| TRSY 4.25% 2046 | 222 | -0.00006 | 0.00928 | -0.03608 | -0.00655 | 0.00040 | 0.00563 | 0.02740 | -0.183 | 0.770 | 0 |
| TRSY 4.25% 2049 | 222 | -0.00004 | 0.00966 | -0.03630 | -0.00664 | 0.00024 | 0.00588 | 0.02868 | -0.175 | 0.788 | 3 |
| TRSY 4.25% 2055 | 222 | -0.00008 | 0.01007 | -0.03899 | -0.00713 | 0.00039 | 0.00601 | 0.03009 | -0.164 | 0.835 | 1 |

| | Panel C: Post-QE1 - 27/01/10-07/10/11 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | Nobs | Mean | Std Dev | Min | Q1 | Median | Q3 | Max | Skew | Excess Kurt | Zeros |
| TRSY 5.25% 2012 | 429 | -0.00011 | 0.00057 | -0.00204 | -0.00042 | -0.00018 | 0.00019 | 0.00203 | 0.174 | 1.342 | 30 |
| TRSY 4.5% 2013 | 429 | -0.00004 | 0.00090 | -0.00277 | -0.00056 | -0.00009 | 0.00055 | 0.00274 | 0.102 | 0.516 | 22 |
| TRSY 8% 2013 | 429 | -0.00012 | 0.00107 | -0.00323 | -0.00078 | -0.00017 | 0.00060 | 0.00336 | 0.093 | 0.450 | 16 |
| TRSY 2.25% 2014 | 429 | 0.00011 | 0.00148 | -0.00435 | -0.00087 | 0.00000 | 0.00113 | 0.00435 | -0.008 | -0.044 | 19 |
| TRSY 5% 2014 | 429 | 0.00004 | 0.00165 | -0.00511 | -0.00099 | 0.00000 | 0.00116 | 0.00488 | -0.020 | -0.022 | 14 |
| TRSY 2.75% 2015 | 429 | 0.00015 | 0.00193 | -0.00591 | -0.00104 | 0.00010 | 0.00150 | 0.00670 | -0.032 | 0.177 | 15 |
| TRSY 4.34% 2015 | 429 | 0.00011 | 0.00210 | -0.00648 | -0.00124 | 0.00000 | 0.00157 | 0.00761 | 0.045 | 0.093 | 6 |
| TRSY 8% 2015 | 429 | 0.00003 | 0.00209 | -0.00643 | -0.00137 | -0.00008 | 0.00149 | 0.00762 | 0.056 | 0.081 | 6 |
| TRSY 4% 2016 | 429 | 0.00018 | 0.00258 | -0.00794 | -0.00155 | 0.00018 | 0.00187 | 0.00988 | 0.057 | 0.104 | 6 |
| TRSY 8.75% 2017 | 429 | 0.00009 | 0.00277 | -0.00779 | -0.00165 | 0.00000 | 0.00204 | 0.01082 | 0.083 | 0.101 | 4 |
| TRSY 5% 2018 | 429 | 0.00021 | 0.00320 | -0.00865 | -0.00184 | 0.00009 | 0.00241 | 0.01242 | 0.093 | 0.058 | 7 |
| TRSY 4.5% 2019 | 429 | 0.00026 | 0.00365 | -0.00985 | -0.00209 | 0.00018 | 0.00282 | 0.01448 | 0.087 | 0.132 | 7 |
| TRSY 3.75% 2019 | 429 | 0.00030 | 0.00391 | -0.01042 | -0.00222 | 0.00019 | 0.00306 | 0.01550 | 0.085 | 0.122 | 5 |
| TRSY 4.75% 2020 | 429 | 0.00027 | 0.00398 | -0.01050 | -0.00229 | 0.00018 | 0.00296 | 0.01580 | 0.109 | 0.156 | 2 |
| TRSY 8% 2021 | 429 | 0.00020 | 0.00408 | -0.01058 | -0.00242 | 0.00015 | 0.00298 | 0.01676 | 0.081 | 0.212 | 6 |
| TRSY 4% 2022 | 429 | 0.00034 | 0.00462 | -0.01218 | -0.00266 | 0.00019 | 0.00332 | 0.01709 | 0.122 | 0.167 | 6 |
| TRSY 5% 2025 | 429 | 0.00036 | 0.00510 | -0.01293 | -0.00274 | 0.00008 | 0.00364 | 0.01941 | 0.226 | 0.429 | 4 |
| TRSY 4.25% 2027 | 429 | 0.00039 | 0.00567 | -0.01402 | -0.00306 | -0.00009 | 0.00386 | 0.02007 | 0.268 | 0.483 | 5 |
| TRSY 6% 2028 | 429 | 0.00034 | 0.00551 | -0.01366 | -0.00280 | 0.00000 | 0.00366 | 0.01953 | 0.251 | 0.560 | 12 |
| TRSY 4.75% 2030 | 429 | 0.00038 | 0.00599 | -0.01655 | -0.00321 | 0.00009 | 0.00391 | 0.02143 | 0.292 | 0.559 | 5 |
| TRSY 4.25% 3032 | 429 | 0.00038 | 0.00637 | -0.01786 | -0.00345 | 0.00000 | 0.00415 | 0.02251 | 0.286 | 0.544 | 6 |
| TRSY 4.5% 2034 | 429 | 0.00039 | 0.00663 | -0.01862 | -0.00359 | 0.00000 | 0.00427 | 0.02316 | 0.287 | 0.539 | 6 |
| TRSY 4.25% 2036 | 429 | 0.00039 | 0.00690 | -0.01971 | -0.00367 | -0.00010 | 0.00424 | 0.02434 | 0.295 | 0.566 | 3 |
| TRSY 4.75% 2038 | 429 | 0.00038 | 0.00711 | -0.02092 | -0.00389 | -0.00019 | 0.00429 | 0.02478 | 0.310 | 0.570 | 2 |
| TRSY 4.25% 2039 | 429 | 0.00039 | 0.00737 | -0.02190 | -0.00403 | -0.00020 | 0.00444 | 0.02540 | 0.307 | 0.587 | 1 |
| TRSY 4.25% 2042 | 429 | 0.00039 | 0.00767 | -0.02343 | -0.00424 | -0.00019 | 0.00453 | 0.02498 | 0.300 | 0.556 | 5 |
| TRSY 4.25% 2046 | 429 | 0.00040 | 0.00821 | -0.02663 | -0.00458 | -0.00020 | 0.00491 | 0.02632 | 0.273 | 0.597 | 4 |
| TRSY 4.25% 2049 | 429 | 0.00040 | 0.00850 | -0.02796 | -0.00481 | -0.00011 | 0.00510 | 0.02706 | 0.261 | 0.605 | 4 |
| TRSY 4.25% 2055 | 429 | 0.00039 | 0.00899 | -0.02997 | -0.00502 | -0.00019 | 0.00536 | 0.02871 | 0.257 | 0.652 | 1 |
| TRSY 4% 2060 | 429 | 0.00041 | 0.00936 | -0.03096 | -0.00508 | 0.00000 | 0.00549 | 0.02980 | 0.229 | 0.729 | 14 |

| | Panel D: QE2&3 - 10/10/11-08/05/13 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | Nobs | Mean | Std Dev | Min | Q1 | Median | Q3 | Max | Skew | Excess Kurt | Zeros |
| TRSY 2.25% 2014 | 400 | -0.00005 | 0.00047 | -0.00125 | -0.00029 | -0.00010 | 0.00019 | 0.00279 | 1.175 | 5.235 | 51 |
| TRSY 5% 2014 | 400 | -0.00013 | 0.00060 | -0.00169 | -0.00046 | -0.00018 | 0.00009 | 0.00329 | 1.021 | 4.288 | 35 |
| TRSY 2.75% 2015 | 400 | -0.00004 | 0.00085 | -0.00235 | -0.00048 | -0.00009 | 0.00045 | 0.00406 | 0.534 | 2.205 | 16 |
| TRSY 4.34% 2015 | 400 | -0.00008 | 0.00105 | -0.00301 | -0.00070 | -0.00009 | 0.00053 | 0.00500 | 0.467 | 1.865 | 17 |
| TRSY 8% 2015 | 400 | -0.00016 | 0.00109 | -0.00321 | -0.00081 | -0.00016 | 0.00047 | 0.00501 | 0.446 | 1.765 | 10 |
| TRSY 2% 2016 | 400 | 0.00003 | 0.00132 | -0.00383 | -0.00076 | 0.00000 | 0.00077 | 0.00591 | 0.305 | 1.273 | 6 |
| TRSY 4% 2016 | 400 | -0.00002 | 0.00152 | -0.00433 | -0.00089 | 0.00000 | 0.00089 | 0.00667 | 0.264 | 1.198 | 10 |
| TRSY 8.75% 2017 | 400 | -0.00011 | 0.00195 | -0.00649 | -0.00126 | -0.00014 | 0.00108 | 0.00839 | 0.231 | 1.584 | 6 |
| TRSY 5% 2018 | 400 | 0.00000 | 0.00231 | -0.00754 | -0.00138 | 0.00000 | 0.00147 | 0.00988 | 0.217 | 1.505 | 10 |
| TRSY 4.5% 2019 | 400 | 0.00005 | 0.00294 | -0.00958 | -0.00183 | 0.00000 | 0.00187 | 0.01276 | 0.184 | 1.518 | 6 |
| TRSY 3.75% 2019 | 400 | 0.00008 | 0.00321 | -0.01031 | -0.00195 | 0.00009 | 0.00205 | 0.01398 | 0.169 | 1.475 | 4 |
| TRSY 4.75% 2020 | 400 | 0.00007 | 0.00341 | -0.01135 | -0.00196 | 0.00016 | 0.00219 | 0.01516 | 0.141 | 1.582 | 3 |
| TRSY 3.75% 2020 | 400 | 0.00010 | 0.00372 | -0.01244 | -0.00219 | 0.00026 | 0.00245 | 0.01766 | 0.163 | 1.797 | 1 |
| TRSY 8% 2021 | 400 | 0.00001 | 0.00375 | -0.01291 | -0.00234 | 0.00013 | 0.00229 | 0.01808 | 0.121 | 1.842 | 5 |
| TRSY 3.75% 2021 | 400 | 0.00011 | 0.00424 | -0.01383 | -0.00253 | 0.00021 | 0.00287 | 0.01982 | 0.101 | 1.715 | 5 |
| TRSY 4% 2022 | 400 | 0.00010 | 0.00436 | -0.01441 | -0.00264 | 0.00017 | 0.00286 | 0.02008 | 0.089 | 1.596 | 5 |
| TRSY 5% 2025 | 400 | 0.00009 | 0.00507 | -0.01697 | -0.00320 | 0.00027 | 0.00330 | 0.02133 | 0.038 | 1.348 | 2 |
| TRSY 4.25% 2027 | 400 | 0.00011 | 0.00584 | -0.01951 | -0.00355 | 0.00017 | 0.00393 | 0.02281 | -0.023 | 1.038 | 6 |
| TRSY 6% 2028 | 400 | 0.00007 | 0.00576 | -0.01914 | -0.00350 | 0.00021 | 0.00384 | 0.02225 | -0.028 | 0.986 | 1 |
| TRSY 4.75% 2030 | 400 | 0.00010 | 0.00630 | -0.02202 | -0.00384 | 0.00031 | 0.00404 | 0.02401 | -0.052 | 1.044 | 3 |
| TRSY 4.25% 3032 | 400 | 0.00012 | 0.00674 | -0.02273 | -0.00431 | 0.00041 | 0.00437 | 0.02560 | -0.037 | 1.024 | 1 |
| TRSY 4.5% 2034 | 400 | 0.00010 | 0.00713 | -0.02380 | -0.00459 | 0.00028 | 0.00448 | 0.02655 | -0.040 | 0.958 | 1 |
| TRSY 4.25% 2036 | 400 | 0.00010 | 0.00744 | -0.02542 | -0.00466 | 0.00050 | 0.00453 | 0.02707 | -0.059 | 0.970 | 3 |
| TRSY 4.75% 2038 | 400 | 0.00009 | 0.00777 | -0.02643 | -0.00503 | 0.00051 | 0.00484 | 0.02754 | -0.066 | 0.907 | 3 |
| TRSY 4.25% 2039 | 400 | 0.00009 | 0.00806 | -0.02741 | -0.00520 | 0.00057 | 0.00506 | 0.02804 | -0.066 | 0.878 | 1 |
| TRSY 4.25% 2040 | 400 | 0.00008 | 0.00824 | -0.02823 | -0.00518 | 0.00054 | 0.00527 | 0.02794 | -0.078 | 0.830 | 1 |
| TRSY 4.25% 2042 | 400 | 0.00007 | 0.00846 | -0.02884 | -0.00547 | 0.00056 | 0.00527 | 0.02774 | -0.089 | 0.763 | 3 |
| TRSY 4.25% 2046 | 400 | 0.00005 | 0.00917 | -0.03147 | -0.00590 | 0.00057 | 0.00576 | 0.02967 | -0.073 | 0.732 | 2 |
| TRSY 4.25% 2049 | 400 | 0.00005 | 0.00955 | -0.03295 | -0.00615 | 0.00049 | 0.00597 | 0.03065 | -0.056 | 0.714 | 1 |
| TRSY 4.25% 2055 | 400 | 0.00006 | 0.01029 | -0.03603 | -0.00665 | 0.00044 | 0.00662 | 0.03299 | -0.039 | 0.689 | 0 |
| TRSY 4% 2060 | 400 | 0.00007 | 0.01090 | -0.03914 | -0.00696 | 0.00042 | 0.00690 | 0.03472 | -0.044 | 0.702 | 1 |

## Table A.2: Autocorrelation statistics

This table contains autocorrelation coefficients for daily returns for lags 1 to 5, AC(1),...,AC(5), and the probability values associated Box and Ljung (1978) portmanteau Q-statistics. The variance ratio statistic is the ratio of the variance of 2-day returns to twice the variance of 1-day returns. The statistic *LM.Het* is Lo and MacKinlay's (1988) variance ratio test statistic that adjusts for heteroscedasticity in the returns data. Under the null hypothesis of randomness, this statistic is distributed N(0,1), providing for a critical value of 1.96 at the 5% significance level. Associated probability values (significance levels) are given in the column headed *LM.Het(p)*. The number of observations is in the column No. Obs. These vary from the full sub-sample value for bonds issued or redeemed within the sub-sample.

| | Panel A: Pre-QE1 - 02/01/04-10/03/09 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | No. Obs. | AC(1) | AC(2) | AC(3) | AC(4) | AC(5) | Q(1) p | Q(2) p | Q(3) p | Q(4) p | Q(5) p | VR(2) | LM.Het. | LM.Het.p |
| TRSY 4.5% 2007 | 775 | 0.0943 | -0.0986 | -0.1104 | 0.0229 | 0.0305 | 0.009 | 0.001 | <0.001 | <0.001 | <0.001 | 1.098 | 1.949 | 0.051 |
| TRSY 8.5% 2007 | 892 | 0.1139 | -0.0804 | -0.0614 | 0.0217 | 0.0376 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 1.120 | 2.553 | 0.011 |
| TRSY 7.25% 2007 | 995 | 0.0968 | -0.0705 | -0.0533 | 0.0282 | 0.0262 | 0.002 | 0.001 | 0.001 | 0.001 | 0.002 | 1.102 | 2.272 | 0.023 |
| TRSY 5% 2008 | 1057 | 0.0964 | -0.0732 | -0.0419 | 0.0260 | 0.0280 | 0.002 | <0.001 | 0.001 | 0.001 | 0.002 | 1.100 | 2.325 | 0.020 |
| TRSY 4% 2009 | 1309 | 0.0878 | -0.0577 | -0.0242 | 0.0274 | 0.0251 | 0.001 | 0.001 | 0.002 | 0.003 | 0.004 | 1.091 | 2.572 | 0.010 |
| TRSY 5.75% 2009 | 1311 | 0.0864 | -0.0415 | -0.0212 | 0.0237 | 0.0188 | 0.002 | 0.002 | 0.005 | 0.009 | 0.016 | 1.089 | 2.834 | 0.005 |
| TRSY 4.75% 2010 | 1087 | 0.0984 | 0.0087 | -0.0160 | 0.0132 | -0.0005 | 0.001 | 0.005 | 0.012 | 0.025 | 0.049 | 1.100 | 3.072 | 0.002 |
| TRSY 6.25% 2010 | 1311 | 0.0877 | -0.0260 | -0.0170 | 0.0141 | 0.0076 | 0.001 | 0.004 | 0.010 | 0.020 | 0.039 | 1.091 | 3.072 | 0.002 |
| TRSY 4.25% 2011 | 843 | 0.0913 | 0.0440 | 0.0059 | -0.0134 | -0.0286 | 0.008 | 0.013 | 0.033 | 0.064 | 0.088 | 1.097 | 2.413 | 0.016 |
| CVSN 9% 2011 | 1311 | 0.0865 | -0.0179 | -0.0137 | 0.0057 | -0.0054 | 0.002 | 0.006 | 0.015 | 0.032 | 0.060 | 1.089 | 2.925 | 0.003 |
| TRSY 5% 2012 | 1311 | 0.0722 | -0.0251 | -0.0152 | 0.0114 | -0.0016 | 0.009 | 0.022 | 0.046 | 0.086 | 0.148 | 1.077 | 2.550 | 0.011 |
| TRSY 5.25% 2012 | 500 | 0.0824 | 0.0382 | -0.0196 | -0.0269 | -0.0384 | 0.065 | 0.125 | 0.226 | 0.318 | 0.362 | 1.087 | 1.821 | 0.069 |
| TRSY 4.5% 2013 | 256 | 0.1097 | -0.0007 | -0.0466 | -0.0060 | -0.0621 | 0.078 | 0.211 | 0.298 | 0.449 | 0.452 | 1.112 | 1.819 | 0.069 |
| TRSY 8% 2013 | 1311 | 0.0606 | -0.0190 | -0.0166 | 0.0212 | -0.0126 | 0.028 | 0.070 | 0.129 | 0.181 | 0.263 | 1.064 | 2.136 | 0.033 |
| TRSY 5% 2014 | 1311 | 0.0501 | -0.0196 | -0.0145 | 0.0291 | -0.0097 | 0.069 | 0.150 | 0.253 | 0.268 | 0.378 | 1.056 | 1.701 | 0.089 |
| TRSY 4.34% 2015 | 1311 | 0.0500 | -0.0231 | -0.0147 | 0.0409 | -0.0067 | 0.070 | 0.137 | 0.234 | 0.167 | 0.258 | 1.057 | 1.534 | 0.125 |
| TRSY 8% 2015 | 1311 | 0.0591 | -0.0195 | -0.0124 | 0.0429 | -0.0079 | 0.032 | 0.079 | 0.152 | 0.103 | 0.168 | 1.065 | 1.603 | 0.109 |
| TRSY 4% 2016 | 769 | 0.0468 | 0.0153 | 0.0014 | 0.0525 | -0.0179 | 0.193 | 0.392 | 0.598 | 0.404 | 0.513 | 1.057 | 0.970 | 0.332 |
| TRSY 8.75% 2017 | 1311 | 0.0577 | -0.0241 | -0.0072 | 0.0485 | -0.0080 | 0.037 | 0.077 | 0.158 | 0.081 | 0.136 | 1.064 | 1.434 | 0.151 |
| TRSY 5% 2018 | 454 | 0.0627 | 0.0001 | -0.0006 | 0.0574 | -0.0305 | 0.180 | 0.407 | 0.615 | 0.506 | 0.587 | 1.077 | 1.059 | 0.289 |
| TRSY 4.75% 2020 | 1004 | 0.0443 | -0.0016 | -0.0209 | 0.0469 | -0.0161 | 0.160 | 0.372 | 0.490 | 0.326 | 0.428 | 1.055 | 1.102 | 0.271 |
| TRSY 8% 2021 | 1311 | 0.0418 | -0.0212 | -0.0169 | 0.0452 | -0.0083 | 0.130 | 0.237 | 0.354 | 0.203 | 0.303 | 1.050 | 1.161 | 0.246 |
| TRSY 5% 2025 | 1311 | 0.0706 | -0.0549 | -0.0314 | 0.0313 | -0.0214 | 0.011 | 0.005 | 0.008 | 0.011 | 0.018 | 1.076 | 0.924 | 0.355 |
| TRSY 4.25% 2027 | 635 | 0.1007 | -0.0483 | -0.0300 | 0.0291 | -0.0458 | 0.011 | 0.019 | 0.036 | 0.059 | 0.064 | 1.108 | 0.857 | 0.391 |
| TRSY 6% 2028 | 1311 | 0.0734 | -0.0608 | -0.0365 | 0.0306 | -0.0210 | 0.008 | 0.003 | 0.003 | 0.005 | 0.008 | 1.078 | 0.941 | 0.347 |
| TRSY 4.25% 3032 | 1311 | 0.0780 | -0.0646 | -0.0455 | 0.0312 | -0.0191 | 0.005 | 0.001 | 0.001 | 0.002 | 0.003 | 1.082 | 1.036 | 0.300 |
| TRSY 4.25% 2036 | 1311 | 0.0740 | -0.0648 | -0.0579 | 0.0338 | -0.0101 | 0.007 | 0.002 | 0.001 | 0.001 | 0.002 | 1.079 | 1.306 | 0.192 |
| TRSY 4.75% 2038 | 1242 | 0.0762 | -0.0733 | -0.0699 | 0.0416 | -0.0140 | 0.007 | 0.001 | <0.001 | <0.001 | <0.001 | 1.079 | 1.378 | 0.168 |
| TRSY 4.25% 2042 | 447 | 0.1079 | -0.0808 | -0.0740 | 0.0487 | -0.0211 | 0.022 | 0.017 | 0.014 | 0.019 | 0.036 | 1.113 | 1.366 | 0.172 |
| TRSY 4.25% 2046 | 716 | 0.0781 | -0.0551 | -0.0803 | 0.0245 | -0.0233 | 0.036 | 0.037 | 0.011 | 0.020 | 0.034 | 1.069 | 0.996 | 0.319 |
| TRSY 4.25% 2055 | 958 | 0.0948 | -0.0834 | -0.0971 | 0.0307 | -0.0131 | 0.003 | <0.001 | <0.001 | <0.001 | <0.001 | 1.093 | 1.608 | 0.108 |

| | Panel B: QE1 - 11/03/09 – 26/01/10 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | No. Obs. | AC(1) | AC(2) | AC(3) | AC(4) | AC(5) | Q(1) p | Q(2) p | Q(3) p | Q(4) p | Q(5) p | VR(1) | LM.Het. | LM.Het.p |
| TRSY 4.25% 2011 | 222 | -0.0249 | 0.0624 | 0.0352 | -0.0969 | -0.0830 | 0.709 | 0.601 | 0.729 | 0.487 | 0.414 | 0.985 | -0.201 | 0.841 |
| CVSN 9% 2011 | 222 | -0.0190 | 0.0882 | 0.0082 | -0.0921 | -0.0685 | 0.776 | 0.399 | 0.603 | 0.435 | 0.433 | 0.992 | -0.118 | 0.906 |
| TRSY 3.25% 2011 | 222 | -0.0137 | 0.0398 | 0.0393 | -0.0852 | -0.1002 | 0.838 | 0.819 | 0.861 | 0.661 | 0.453 | 0.996 | -0.061 | 0.951 |
| TRSY 5% 2012 | 222 | -0.0497 | 0.0546 | 0.0388 | -0.0881 | -0.0691 | 0.456 | 0.540 | 0.666 | 0.502 | 0.488 | 0.958 | -0.581 | 0.561 |
| TRSY 5.25% 2012 | 222 | -0.0542 | 0.0577 | 0.0312 | -0.0762 | -0.0702 | 0.416 | 0.493 | 0.652 | 0.565 | 0.537 | 0.953 | -0.664 | 0.507 |
| TRSY 4.5% 2013 | 222 | -0.1269 | 0.0315 | 0.0664 | -0.0515 | -0.0312 | 0.057 | 0.146 | 0.183 | 0.244 | 0.339 | 0.880 | -1.459 | 0.144 |
| TRSY 8% 2013 | 222 | -0.0407 | 0.0351 | 0.0348 | -0.0201 | -0.0575 | 0.541 | 0.722 | 0.819 | 0.907 | 0.879 | 0.967 | -0.486 | 0.627 |
| TRSY 2.25% 2014 | 214 | -0.0984 | -0.0305 | 0.0800 | -0.0043 | -0.1025 | 0.147 | 0.316 | 0.295 | 0.446 | 0.303 | 0.898 | -1.396 | 0.163 |
| TRSY 5% 2014 | 222 | -0.0492 | -0.0815 | 0.0249 | -0.0038 | -0.0835 | 0.461 | 0.360 | 0.535 | 0.701 | 0.581 | 0.955 | -0.627 | 0.531 |
| TRSY 4.34% 2015 | 222 | 0.0189 | -0.0547 | -0.0119 | -0.0667 | -0.0825 | 0.777 | 0.685 | 0.852 | 0.772 | 0.644 | 1.020 | 0.270 | 0.787 |
| TRSY 8% 2015 | 222 | 0.0055 | -0.0481 | 0.0037 | -0.0593 | -0.0633 | 0.934 | 0.767 | 0.911 | 0.855 | 0.813 | 1.002 | 0.035 | 0.972 |
| TRSY 4% 2016 | 222 | 0.0060 | -0.0713 | -0.0065 | -0.0419 | -0.0372 | 0.929 | 0.560 | 0.761 | 0.815 | 0.865 | 1.003 | 0.044 | 0.965 |
| TRSY 8.75% 2017 | 222 | 0.0314 | -0.0867 | -0.0192 | -0.0651 | -0.0407 | 0.638 | 0.383 | 0.571 | 0.562 | 0.646 | 1.025 | 0.352 | 0.725 |
| TRSY 5% 2018 | 222 | 0.0367 | -0.0946 | -0.0250 | -0.0565 | -0.0397 | 0.582 | 0.313 | 0.481 | 0.526 | 0.615 | 1.035 | 0.500 | 0.617 |
| TRSY 4.5% 2019 | 222 | -0.0096 | -0.0759 | -0.0213 | -0.0573 | -0.0315 | 0.886 | 0.516 | 0.700 | 0.704 | 0.791 | 0.982 | -0.262 | 0.793 |
| TRSY 4.75% 2020 | 222 | 0.0169 | -0.0901 | -0.0259 | -0.0516 | -0.0294 | 0.800 | 0.387 | 0.562 | 0.616 | 0.722 | 1.013 | 0.195 | 0.845 |
| TRSY 8% 2021 | 222 | 0.0045 | -0.0857 | -0.0191 | -0.0572 | -0.0459 | 0.947 | 0.435 | 0.627 | 0.646 | 0.703 | 1.001 | 0.011 | 0.991 |
| TRSY 4% 2022 | 222 | 0.0123 | -0.0970 | -0.0293 | -0.0406 | -0.0495 | 0.854 | 0.339 | 0.502 | 0.603 | 0.655 | 1.007 | 0.097 | 0.923 |
| TRSY 5% 2025 | 222 | 0.0648 | -0.0795 | -0.0606 | -0.0332 | 0.0284 | 0.331 | 0.305 | 0.361 | 0.484 | 0.602 | 1.033 | 0.485 | 0.628 |
| TRSY 4.25% 2027 | 222 | 0.0795 | -0.0759 | -0.0629 | -0.0247 | 0.0400 | 0.233 | 0.256 | 0.305 | 0.439 | 0.531 | 1.042 | 0.625 | 0.532 |
| TRSY 6% 2028 | 222 | 0.0416 | -0.0428 | -0.0678 | -0.0238 | 0.0393 | 0.533 | 0.669 | 0.605 | 0.740 | 0.802 | 1.007 | 0.115 | 0.909 |
| TRSY 4.75% 2030 | 222 | 0.0347 | -0.0646 | -0.0763 | -0.0153 | 0.0449 | 0.603 | 0.545 | 0.469 | 0.629 | 0.692 | 1.005 | 0.078 | 0.938 |
| TRSY 4.25% 3032 | 222 | 0.0541 | -0.0887 | -0.0762 | -0.0149 | 0.0463 | 0.417 | 0.295 | 0.289 | 0.433 | 0.507 | 1.023 | 0.333 | 0.739 |
| TRSY 4.25% 2036 | 222 | 0.0386 | -0.0796 | -0.1093 | -0.0153 | 0.0352 | 0.563 | 0.413 | 0.214 | 0.339 | 0.438 | 1.021 | 0.309 | 0.757 |
| TRSY 4.75% 2038 | 222 | 0.0329 | -0.0852 | -0.1213 | -0.0055 | 0.0455 | 0.622 | 0.390 | 0.156 | 0.264 | 0.336 | 1.016 | 0.228 | 0.820 |
| TRSY 4.25% 2039 | 222 | 0.0384 | -0.0834 | -0.1227 | -0.0028 | 0.0494 | 0.565 | 0.386 | 0.149 | 0.255 | 0.317 | 1.023 | 0.327 | 0.744 |
| TRSY 4.25% 2042 | 222 | 0.0246 | -0.0850 | -0.1196 | -0.0009 | 0.0331 | 0.712 | 0.413 | 0.170 | 0.285 | 0.384 | 1.011 | 0.155 | 0.877 |
| TRSY 4.25% 2046 | 222 | 0.0192 | -0.0829 | -0.1269 | 0.0089 | 0.0349 | 0.774 | 0.441 | 0.152 | 0.257 | 0.348 | 1.007 | 0.102 | 0.919 |
| TRSY 4.25% 2049 | 222 | 0.0047 | -0.0557 | -0.1344 | 0.0002 | 0.0179 | 0.943 | 0.702 | 0.186 | 0.307 | 0.430 | 0.996 | -0.054 | 0.957 |
| TRSY 4.25% 2055 | 222 | 0.0227 | -0.0697 | -0.1322 | 0.0070 | 0.0282 | 0.733 | 0.545 | 0.159 | 0.268 | 0.372 | 1.012 | 0.167 | 0.867 |

| | Panel C: Post-QE1 - 27/01/10-07/10/11 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | No. Obs. | AC(1) | AC(2) | AC(3) | AC(4) | AC(5) | Q(1) p | Q(2) p | Q(3) p | Q(4) p | Q(5) p | VR(1) | LM.Het. | LM.Het.p |
| TRSY 5.25% 2012 | 429 | -0.0135 | -0.0582 | 0.0010 | 0.0299 | -0.0995 | 0.779 | 0.462 | 0.672 | 0.748 | 0.282 | 0.975 | -0.436 | 0.663 |
| TRSY 4.5% 2013 | 429 | 0.0344 | -0.0567 | 0.0284 | 0.0698 | -0.1165 | 0.474 | 0.386 | 0.521 | 0.358 | 0.067 | 1.031 | 0.582 | 0.560 |
| TRSY 8% 2013 | 429 | 0.0259 | -0.0662 | 0.0254 | 0.0836 | -0.1184 | 0.590 | 0.335 | 0.481 | 0.239 | 0.040 | 1.024 | 0.463 | 0.643 |
| TRSY 2.25% 2014 | 429 | 0.0390 | -0.0563 | 0.0201 | 0.0815 | -0.0892 | 0.417 | 0.362 | 0.531 | 0.278 | 0.128 | 1.040 | 0.809 | 0.418 |
| TRSY 5% 2014 | 429 | 0.0409 | -0.0465 | 0.0203 | 0.0751 | -0.0943 | 0.395 | 0.437 | 0.607 | 0.369 | 0.147 | 1.043 | 0.887 | 0.375 |
| TRSY 2.75% 2015 | 429 | 0.0532 | -0.0613 | -0.0054 | 0.0868 | -0.0565 | 0.269 | 0.241 | 0.414 | 0.189 | 0.184 | 1.056 | 1.153 | 0.249 |
| TRSY 4.34% 2015 | 429 | 0.0397 | -0.0554 | 0.0189 | 0.0876 | -0.0733 | 0.410 | 0.367 | 0.540 | 0.240 | 0.165 | 1.042 | 0.871 | 0.384 |
| TRSY 8% 2015 | 429 | 0.0390 | -0.0587 | 0.0206 | 0.0896 | -0.0721 | 0.418 | 0.342 | 0.507 | 0.213 | 0.151 | 1.042 | 0.866 | 0.386 |
| TRSY 4% 2016 | 429 | 0.0440 | -0.0808 | 0.0217 | 0.0860 | -0.0714 | 0.361 | 0.160 | 0.276 | 0.131 | 0.097 | 1.049 | 1.010 | 0.313 |
| TRSY 8.75% 2017 | 429 | 0.0337 | -0.0970 | -0.0102 | 0.0792 | -0.0268 | 0.484 | 0.102 | 0.203 | 0.119 | 0.177 | 1.034 | 0.693 | 0.488 |
| TRSY 5% 2018 | 429 | 0.0316 | -0.0923 | -0.0171 | 0.0696 | -0.0129 | 0.512 | 0.128 | 0.236 | 0.174 | 0.267 | 1.032 | 0.643 | 0.520 |
| TRSY 4.5% 2019 | 429 | 0.0366 | -0.0953 | -0.0200 | 0.0698 | -0.0287 | 0.447 | 0.105 | 0.196 | 0.146 | 0.209 | 1.037 | 0.741 | 0.459 |
| TRSY 3.75% 2019 | 429 | 0.0336 | -0.0973 | -0.0312 | 0.0678 | -0.0208 | 0.484 | 0.101 | 0.171 | 0.135 | 0.206 | 1.034 | 0.682 | 0.495 |
| TRSY 4.75% 2020 | 429 | 0.0377 | -0.0900 | -0.0358 | 0.0719 | -0.0034 | 0.433 | 0.127 | 0.197 | 0.140 | 0.226 | 1.038 | 0.739 | 0.460 |
| TRSY 8% 2021 | 429 | 0.0427 | -0.0743 | -0.0415 | 0.0691 | -0.0138 | 0.374 | 0.204 | 0.269 | 0.199 | 0.298 | 1.038 | 0.741 | 0.459 |
| TRSY 4% 2022 | 429 | 0.0385 | -0.0930 | -0.0382 | 0.0684 | -0.0167 | 0.424 | 0.111 | 0.170 | 0.133 | 0.208 | 1.040 | 0.749 | 0.454 |
| TRSY 5% 2025 | 429 | 0.0501 | -0.0887 | -0.0488 | 0.0577 | -0.0202 | 0.298 | 0.106 | 0.138 | 0.138 | 0.210 | 1.055 | 0.971 | 0.331 |
| TRSY 4.25% 2027 | 429 | 0.0735 | -0.1052 | -0.0548 | 0.0572 | -0.0072 | 0.126 | 0.028 | 0.038 | 0.043 | 0.079 | 1.078 | 1.333 | 0.182 |
| TRSY 6% 2028 | 429 | 0.0744 | -0.0881 | -0.0666 | 0.0438 | 0.0121 | 0.122 | 0.056 | 0.053 | 0.075 | 0.127 | 1.078 | 1.335 | 0.182 |
| TRSY 4.75% 2030 | 429 | 0.0746 | -0.1088 | -0.0634 | 0.0513 | -0.0043 | 0.121 | 0.023 | 0.026 | 0.034 | 0.064 | 1.079 | 1.322 | 0.186 |
| TRSY 4.25% 3032 | 429 | 0.0735 | -0.1139 | -0.0681 | 0.0501 | -0.0121 | 0.126 | 0.019 | 0.019 | 0.026 | 0.049 | 1.078 | 1.292 | 0.196 |
| TRSY 4.5% 2034 | 429 | 0.0678 | -0.1175 | -0.0697 | 0.0509 | -0.0152 | 0.159 | 0.019 | 0.018 | 0.024 | 0.046 | 1.071 | 1.179 | 0.238 |
| TRSY 4.25% 2036 | 429 | 0.0708 | -0.1191 | -0.0743 | 0.0434 | -0.0230 | 0.141 | 0.016 | 0.013 | 0.021 | 0.038 | 1.075 | 1.227 | 0.220 |
| TRSY 4.75% 2038 | 429 | 0.0674 | -0.1191 | -0.0796 | 0.0396 | -0.0287 | 0.161 | 0.017 | 0.013 | 0.021 | 0.036 | 1.071 | 1.153 | 0.249 |
| TRSY 4.25% 2039 | 429 | 0.0651 | -0.1205 | -0.0844 | 0.0358 | -0.0250 | 0.176 | 0.017 | 0.011 | 0.019 | 0.034 | 1.069 | 1.104 | 0.269 |
| TRSY 4.25% 2042 | 429 | 0.0595 | -0.1196 | -0.0836 | 0.0389 | -0.0339 | 0.217 | 0.021 | 0.013 | 0.022 | 0.036 | 1.062 | 1.004 | 0.316 |
| TRSY 4.25% 2046 | 429 | 0.0591 | -0.1255 | -0.0837 | 0.0438 | -0.0343 | 0.219 | 0.016 | 0.010 | 0.016 | 0.026 | 1.061 | 0.993 | 0.321 |
| TRSY 4.25% 2049 | 429 | 0.0605 | -0.1229 | -0.0945 | 0.0470 | -0.0307 | 0.209 | 0.017 | 0.007 | 0.011 | 0.020 | 1.062 | 1.004 | 0.316 |
| TRSY 4.25% 2055 | 429 | 0.0516 | -0.1328 | -0.0875 | 0.0452 | -0.0363 | 0.284 | 0.012 | 0.007 | 0.011 | 0.019 | 1.052 | 0.839 | 0.401 |
| TRSY 4% 2060 | 429 | 0.0489 | -0.1253 | -0.0944 | 0.0404 | -0.0136 | 0.310 | 0.020 | 0.008 | 0.015 | 0.029 | 1.048 | 0.768 | 0.443 |

| | Panel D: QE2&3 - 10/10/11-08/05/13 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bond Name | No. Obs. | AC(1) | AC(2) | AC(3) | AC(4) | AC(5) | Q(1) p | Q(2) p | Q(3) p | Q(4) p | Q(5) p | VR(1) | LM.Het. | LM.Het.p |
| TRSY 2.25% 2014 | 400 | -0.1960 | -0.0334 | -0.0029 | 0.0300 | 0.0120 | <0.001 | <0.001 | 0.001 | 0.003 | 0.006 | 0.805 | -2.797 | 0.005 |
| TRSY 5% 2014 | 400 | -0.1667 | -0.0354 | -0.0098 | 0.0294 | 0.0340 | 0.001 | 0.003 | 0.008 | 0.017 | 0.028 | 0.832 | -2.535 | 0.011 |
| TRSY 2.75% 2015 | 400 | -0.0641 | -0.0878 | -0.0910 | 0.0363 | 0.0128 | 0.198 | 0.092 | 0.043 | 0.070 | 0.120 | 0.936 | -1.005 | 0.315 |
| TRSY 4.34% 2015 | 400 | -0.0461 | -0.0651 | -0.0883 | 0.0258 | 0.0086 | 0.355 | 0.277 | 0.126 | 0.199 | 0.304 | 0.955 | -0.718 | 0.473 |
| TRSY 8% 2015 | 400 | -0.0591 | -0.0628 | -0.0852 | 0.0319 | 0.0124 | 0.235 | 0.223 | 0.115 | 0.174 | 0.268 | 0.940 | -0.967 | 0.334 |
| TRSY 2% 2016 | 400 | -0.0066 | -0.0707 | -0.0979 | 0.0281 | -0.0126 | 0.894 | 0.361 | 0.115 | 0.182 | 0.277 | 0.997 | -0.054 | 0.957 |
| TRSY 4% 2016 | 400 | -0.0071 | -0.0590 | -0.0964 | 0.0295 | -0.0056 | 0.887 | 0.491 | 0.159 | 0.236 | 0.352 | 0.996 | -0.063 | 0.950 |
| TRSY 8.75% 2017 | 400 | 0.0196 | -0.0866 | -0.1154 | 0.0403 | -0.0124 | 0.695 | 0.203 | 0.035 | 0.055 | 0.098 | 1.020 | 0.298 | 0.766 |
| TRSY 5% 2018 | 400 | 0.0142 | -0.0826 | -0.1216 | 0.0477 | -0.0228 | 0.775 | 0.242 | 0.032 | 0.045 | 0.076 | 1.016 | 0.247 | 0.805 |
| TRSY 4.5% 2019 | 400 | 0.0037 | -0.0858 | -0.1243 | 0.0708 | -0.0119 | 0.941 | 0.225 | 0.026 | 0.024 | 0.045 | 1.004 | 0.056 | 0.955 |
| TRSY 3.75% 2019 | 400 | 0.0047 | -0.0887 | -0.1262 | 0.0700 | -0.0103 | 0.926 | 0.203 | 0.022 | 0.020 | 0.040 | 1.004 | 0.059 | 0.953 |
| TRSY 4.75% 2020 | 400 | 0.0029 | -0.0938 | -0.1337 | 0.0654 | -0.0101 | 0.954 | 0.169 | 0.013 | 0.014 | 0.028 | 1.002 | 0.036 | 0.971 |
| TRSY 3.75% 2020 | 400 | 0.0064 | -0.0936 | -0.1350 | 0.0654 | -0.0069 | 0.898 | 0.169 | 0.012 | 0.013 | 0.026 | 1.006 | 0.094 | 0.925 |
| TRSY 8% 2021 | 400 | 0.0056 | -0.1107 | -0.1383 | 0.0734 | <0.0001 | 0.910 | 0.084 | 0.005 | 0.005 | 0.011 | 1.008 | 0.117 | 0.907 |
| TRSY 3.75% 2021 | 400 | 0.0149 | -0.0969 | -0.1440 | 0.0633 | -0.0074 | 0.766 | 0.143 | 0.006 | 0.008 | 0.016 | 1.014 | 0.211 | 0.833 |
| TRSY 4% 2022 | 400 | 0.0077 | -0.0939 | -0.1385 | 0.0617 | -0.0061 | 0.878 | 0.166 | 0.010 | 0.012 | 0.024 | 1.005 | 0.086 | 0.932 |
| TRSY 5% 2025 | 400 | 0.0009 | -0.0965 | -0.1413 | 0.0691 | 0.0022 | 0.985 | 0.152 | 0.008 | 0.008 | 0.017 | 1.000 | -0.007 | 0.994 |
| TRSY 4.25% 2027 | 400 | 0.0071 | -0.1004 | -0.1481 | 0.0735 | 0.0280 | 0.886 | 0.129 | 0.005 | 0.004 | 0.008 | 1.004 | 0.069 | 0.945 |
| TRSY 6% 2028 | 400 | 0.0091 | -0.0978 | -0.1500 | 0.0710 | 0.0278 | 0.856 | 0.142 | 0.005 | 0.005 | 0.009 | 1.006 | 0.098 | 0.922 |
| TRSY 4.75% 2030 | 400 | 0.0227 | -0.1144 | -0.1579 | 0.0896 | 0.0318 | 0.648 | 0.064 | 0.001 | 0.001 | 0.002 | 1.017 | 0.294 | 0.769 |
| TRSY 4.25% 3032 | 400 | 0.0211 | -0.1160 | -0.1572 | 0.0882 | 0.0294 | 0.672 | 0.060 | 0.001 | 0.001 | 0.002 | 1.015 | 0.261 | 0.794 |
| TRSY 4.5% 2034 | 400 | 0.0182 | -0.1194 | -0.1614 | 0.0853 | 0.0325 | 0.714 | 0.053 | 0.001 | 0.001 | 0.001 | 1.012 | 0.209 | 0.834 |
| TRSY 4.25% 2036 | 400 | 0.0195 | -0.1212 | -0.1633 | 0.0852 | 0.0318 | 0.696 | 0.048 | 0.001 | 0.001 | 0.001 | 1.014 | 0.235 | 0.814 |
| TRSY 4.75% 2038 | 400 | 0.0191 | -0.1208 | -0.1695 | 0.0840 | 0.0325 | 0.701 | 0.049 | 0.001 | <0.001 | 0.001 | 1.013 | 0.216 | 0.829 |
| TRSY 4.25% 2039 | 400 | 0.0203 | -0.1207 | -0.1711 | 0.0823 | 0.0306 | 0.684 | 0.049 | <0.001 | <0.001 | 0.001 | 1.014 | 0.237 | 0.813 |
| TRSY 4.25% 2040 | 400 | 0.0208 | -0.1213 | -0.1714 | 0.0847 | 0.0295 | 0.677 | 0.047 | <0.001 | <0.001 | 0.001 | 1.014 | 0.230 | 0.818 |
| TRSY 4.25% 2042 | 400 | 0.0232 | -0.1206 | -0.1730 | 0.0857 | 0.0282 | 0.642 | 0.047 | <0.001 | <0.001 | 0.001 | 1.016 | 0.279 | 0.780 |
| TRSY 4.25% 2046 | 400 | 0.0246 | -0.1209 | -0.1717 | 0.0876 | 0.0263 | 0.621 | 0.046 | <0.001 | <0.001 | 0.001 | 1.018 | 0.305 | 0.761 |
| TRSY 4.25% 2049 | 400 | 0.0284 | -0.1227 | -0.1701 | 0.0859 | 0.0260 | 0.568 | 0.041 | <0.001 | <0.001 | 0.001 | 1.023 | 0.381 | 0.703 |
| TRSY 4.25% 2055 | 400 | 0.0328 | -0.1202 | -0.1705 | 0.0893 | 0.0190 | 0.511 | 0.044 | <0.001 | <0.001 | 0.001 | 1.026 | 0.448 | 0.654 |
| TRSY 4% 2060 | 400 | 0.0367 | -0.1196 | -0.1674 | 0.0866 | 0.0163 | 0.461 | 0.042 | 0.001 | <0.001 | 0.001 | 1.030 | 0.500 | 0.617 |